DEVELOPMENT OF EXPERT SYSTEM FOR UNDERCARRIAGE DESIGN

by

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INDIAN INSTITUTE OF TECHNOLOGY, KANPUR

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DEDICATED

TO

MY PARENTS

CERTIFICATE

This is to certify that the work entitled 'Development of Expert System for Undercarriage design' by Arun Kumar has been carried out under my supervision and has not been submitted elsewhere for the award of a degree.

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CONTENTS

ABSTRACT

An expert system for the design of aircraft undercarriage has been developed. The system has high degree of flexibility, which helps the user in comparative study of the design with slight changes in design parameters. It may be used as a teaching aid for beginner and an effective tool for an experienced designer.

The expert system works on the basis of logic programming. The predicate calculus used is hornclauses. The knowledgebase of the expert system consists of undercarriage design processes coded into 'if-then' rules.

The design details that has been coded into the database are, tyre design, wheel design, and brake design. It incorporates procedures used for the selections of, type of landing gear, tyre pressure, tyre size, brake system and shock absorber

It is possible to get a design detail for any type of requirement without designing the undercarriage completely, after the system has generated experience with sufficiently many number of times.

NOMENCLATURE

A_c	Area of contact, equation (3.17)
AD	Diameter of solid axle, equation (3.12)
AD_o	Outer diameter of hallow axle, equation (3.13)
a	Deceleration due to braking
D	Outside diameter of tyre, equation (3.10)
d	Wheel rim diameter, equation (3.10)
e_s	Static deflection of the tyre plus shock absorber, equation (3.4)
F	Friction force between ground and tyre
F_1	Friction force per wheel
F_{TBL}	Total outward bursting force, equation (3.10)
F_{TH}	Flange thickness of wheelrim, equation (3.11)
f	Friction coefficient between ground and tyre
f_s	Friction coefficient of braking material
g	Acceleration due to gravity
h_{cg}	Height of centre of gravity from ground
k	Drag loss factor, equation (3.15)
KE_1	Kinetic energy per wheel
L	Maximum load developed during the landing
M	Bending moment developed in the axle
N	Total number of tyres in an aircraft
n	Percentage weight acting on the auxillary wheel

p	Inflation pressure of the tyre, equation (3.10)
r	Tyre section radius, equation (3.10)
S	Stroke of the shock absorber
s	Allowable design stress
s_{max}	Maximum design stress
θ	Overturning angle, the angle between the vertical and the line joining the centre of gravity to the main wheel centre in side view.
θ_{TD}	Overturning angle at the time of touch down.
θ_c	Angle of contact
ϕ	Stability angle, the angle between the vertical and the line joining the centre of gravity to the main wheel centre in front view.
V	Aircraft's speed at the time of brake application
W	Maximum weight of the aircraft
$W1$	Dynamic load on each leg
WB	Wheelbase of the aircraft
WT	Wheeltrack of the aircraft
X_1	Distance between the centre of gravity and the front wheel
X_2	Distance between the centre of gravity and the rear wheel.

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 EXPERT SYSTEM AND ITS MODEL

Computer programs used in engineering do not learn anything from the data they process. That is the additional knowledge contained in the results is not fed back to improve the process. Artificial Intelligence[1] (AI) is the branch of computer science which addresses the problems of incorporating knowledge into computer programs. For average engineering applications, AI becomes most important as it aids the 'human' designer. Using AI techniques, one can simulate the human cognitive ability and expertise of an experienced designer in an interactive computer program called EXPERT SYSTEMS.

EXPERT SYSTEM:

Expert system may be defined as [2] 'a problem-solving program that solves substantial problems which are generally solved by human experts'. Expert system can also be defined[3] as 'that which provides human users with expert conclusions about specialized subject areas'. Hitoshi Furuta[4] defines, 'expert system is a useful tool for solving ill-defined problems such as those in structural design, where intuition and experience are necessary ingredients'.

Most expert systems comprise of:

- An input-output interface with the ability to explain or advise
- A knowledge base containing the facts, beliefs, assumptions and heuristics which form the basis of the expertise (in brief, a large knowledge domain).
- Acquiring more and more knowledge and increasing knowledge doma
- Flexibility to change or modify the knowledge base and, or, solution domain.

In an expert system, the knowledge of an expert is express as a large set of simple rules, together with a set of assertions It uses an inference 'engine' that works on the knowledge domain and arrives at a conclusion. It engages in a dialogue with the user to acquire the relevant details of the problem, directly or indirectly, and explains problem-solving process. Schematica the expert system can be represented as shown in fig. 1.1.

The expert system can be effectively used in engineering field. Here, the aim is to blend the computer and the user into an effective system. This means that the user will retain the chall or creative part of the task, while the expert system helps him best utilize his imagination.

By now, the expert system has had use in the fields of medical diagnosis[5], mineral exploration[6] and for analyzing

performance of electronic circuits[7]. Development of expert systems in the area of structural engineering is in progress, like the recently developed SACON[10] Package which interacts with the user for the proper application of MARC[10] finite element structural analysis program.

1.2 AIRCRAFT STRUCTURAL DESIGN

Aircraft design and development have become a matter of large investment. The manhours required have increased considerably in recent years and gone are the days when a single desig could consider himself as the 'spiritual' father of a new aircraf type. Also design is not a deterministic process, particularly in the early stages in which the conception is realized, various solutions to attain the desired goal will present themselves. If it proves impossible to weigh up the pros and cons and arrive at a realistic answer, based on the intuition and experience of designer(s), comparative studies will have to be undertaken. Since it will generally not be found feasible to transform all likely configurations into fully developed projects, a parametri design phase is often decided upon. This first entails the deve ment of an initial baseline design. The next step is to check to what extent the characteristics and performance of the design will meet the design requirements. Changes are now made in this baseline design in systematic manner, thus emerge a family of designs which are comparable with each other. The object of this exercise is to meet the requirement and to investigate the most

likely possibilities and see whether other variants may prove to be a better proposal. It may also show that changes in the design requirements would yield a better overall balance. Thus alteration of earlier designs of some parts may be essential depending upon the changes made in parametric design.

A general arrangement of a new design can be finally drafted after the location of the parts, say, wings, engines, tail surfaces and landing gear, has been made from the number of choices that are available. After fixing the locations the selections of the parts from the available options have to be made. To cite a few examples: wings are of different types like high wing, low wing and mid wing; in tail plane arrangements there are single fin with stabilizer mounted on the fusela twin vertical tails, V or Butterfly tail; in landing gear types there are nose wheel type, tail wheel type, and bicycle wheel type.

Hence, to suggest a design, it needs an experties in each of the domains. The above complicated design approach can be best tackled by the expert system.

1.3 OBJECTIVE OF PRESENT WORK

The present work, which deals with the undercarriage design of aircrafts, is an example to show how effectively an expert system approach can be adopted for aircraft structural design.

Some of the features of the program developed are mentioned below.

- It gains 'experience' in each run.
- When the designer presents the purpose and weight of the aircraft, he is provided with a design without any further details required from him.
- This is done because of the earlier experience the program has gained in solving similar type of problem.
- If no design has been done under that category the user will be so informed and the program starts a new design.
- If the user is satisfied with the present design, he can retain the same.
- If he wishes to see if there are any other designs under same category he can do so.
- If he wishes to alter any one of the available designs by changing one or all the design parameters, that can also be achieved. It may be noted that this is the feature most of the aircraft designers would like to have, which would provide them a means for comparative study.
- If he wishes to have a new design altogether, then it can be done.

Fig. 1.2 helps in better understanding of the working of the present problem. Apart from these features all other featu

of expert system like selections, helping in decisions, accepting partial data, user-friendliness, etc. are there.

An experienced designer can use this as an aid for his designing, whereas a beginner can use this as a teaching aid.

1.4 THESIS LAYOUT

The general layout of the thesis is presented below. The method of working and the tools available in the inference system 'VIDHI' are explained in the second chapter. Chapter 3, explains the basic design procedure of the undercarriage with the schemes used in making decisions and selections. Discussion regarding how the knowledge and experience have been coded into the knowledge base is in chapter 4. Chapter 5, presents the outcome of the exercise for a few different illustrative conditions and putsforth suggestions for the future work.

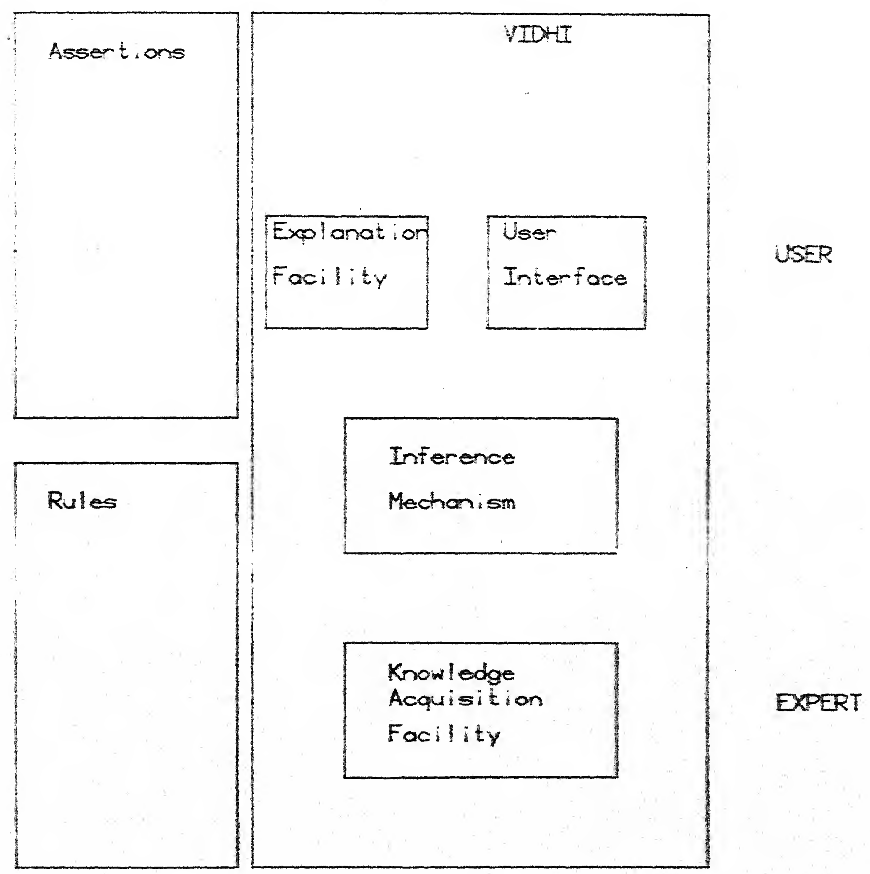


Fig. 1.1 EXPERT SYSTEM MODEL

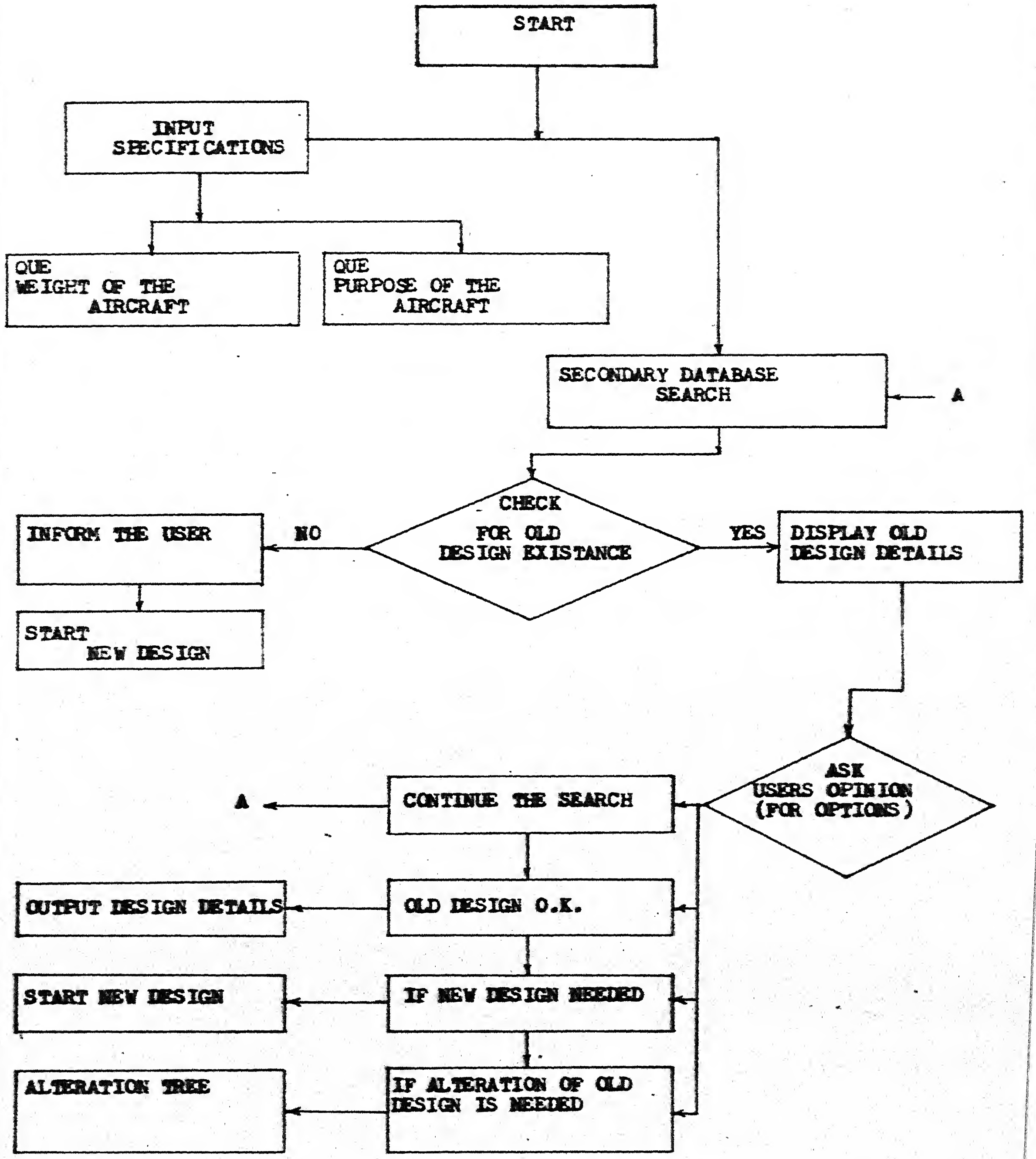


Fig.1.2 BLOCK DIAGRAM OF MAIN FRAME

CHAPTER 2

INTERPRETER - THE VIDHI

2.1 INTRODUCTION

In any expert system the knowledge about the domain must be separate from how that knowledge is to be applied or used. The knowledge should be represented declaratively, and a separate prescriptive component should select and apply it.[2] For a problem the system consists of two major components:

1. a knowledgebase consisting of 'if-then' rules,
2. an interpreter, also called as an expert system shell, which decides what is to be done next.

In the present work the shell is named as VIDHI, developed based on logic programming by Dr. R. Sangal of Computer Science and Engg. Department of I.I.T. Kanpur. The programming language used in VIDHI is CLISP.

2.2 LOGIC PROGRAMMING

Logic programming used here is based on a subset of first-order predicate calculus namely the horn clauses. It is used for solving problems involving objects and relationship. Predicates are used to express relations between objects for example, to express the relationship between father and mother, the predicates are used as follows:

Father (Rama, Mohan)

Mother (Seeta, Mohan)

The above predicates mean, Rama is Mohan's father and Seeta is Mohan's mother. The above predicates are called as two-place predicate. It can also be represented in list notation as follows,

(Father Rama Mohan)

(Mother Seeta Mohan)

In VIDHI later type is used.

2.2.1 Pattern matching

The representation of knowledge can be divided into 2 types:

a. Pattern which can have zero or more occurence of the wild card and,

b. A data item or a fact which does not have a wild card, where a wild card is a variable which can take any value. For example

1. (Father Rama Mohan)
2. (Father Aravind Ashok)

are some examples of items or facts. Here Father is a predicate which has two arguments. Same predicate has been used to represent different relationship, that indicates arguments can take different values or names. Similarly, if we have a wild card

in place of arguments, like

3. (Father Rama ?Son)

4. (Father ?X Mohan)

5. (Father ?X ?Y)

then these are called as patterns.

When pattern and items are matched, we get a value for the wild card provided the name of the predicate is same and non wild card arguments in the pattern and item are same. In the above case when item (1) is matched for pattern (3) we get ?

?SON = Mohan.

Whereas if we match item (2) with pattern (3) the matching will fail, since the first argument is different. Pattern (5) can be matched to both the items (1) and (2). In logic programming the pattern matching concept can be successfully adopted.

2.2.2 Formulas

Two types of objects are defined here terms and formulas. Terms occur as arguments of predicates in formulas and usually denote things. A formula on the other hand takes a truth value. Both make use of symbolic atoms which are a sequence of alpha-numeric characters beginning with a non-numeric character.

A term is one of the following:

a variable: a symbolic atom beginning with a '?'

a constant: a symbolic atom not beginning with a '?' or a number.

a function - argument combination: a list of the form

(<f><p1> ... ... <pn>)

where <f> is a function symbol (a constant) and <p1> to <pn> are arguments (terms).

A formula can take any one of the following two forms:

i. An atomic formula is a predicate - argument combination, where the predicate is a symbolic atom and the arguments are terms. It is represented as a list.

For example,

(Father Ram Mohan).

ii. A horn clause (formula) is of the form

$$Q \leftarrow P_1 \ldots . Pn \qquad n >= 0 \qquad \ldots \qquad (a)$$

where Q and P_1 to P_n are atomic formulas. Q is called as consequent, and P_1 to Pn are called the antecedent. If the antecedent is empty, it reduces to an atomic formula.

For example,

```
(PARTS-DESIGN  ?MAIN)<- (PRESSURE-SELECTION  ?MAIN)
                        (TYRE-SELECTION  ?MAIN)
```

Formulas take truth values. For example, in formula (a), Q is true whenever each member of P_1 to Pn is true.

2.2.3 Inference

Inference will allow us to infer new facts from the database, which proceeds by instantiation and modus ponens, means application of rules.

When a query is floated, it is checked with a fact, if it is there. If yes, the query can be answered to be true. If the matching with facts fails, then matching with the LHS of rules are tried. If a rule matches, the atomic formulas in its RHS after proper instantiation become the new sub-goals, and same procedure as above is repeated. In case of failure to match a subgoal, another rule will be tried. This process repeats until either we are successful, or no more rules remain to be tried. An example to cite the idea clearly

1. (STORAGE-1 A1 1500 NOSE)
2. (STORAGE-1 A2 2500 NOSE)
3. (STORAGE-1 A2 2500 TAIL)
4. (STORAGE-1 ?AA ?WT ?TYPE) <-
   (TYPE-OF-AC ?TYPE ?WT)
   (PURPOSE-OF-AC ?WT ?AA)
5. (TYPE-OF-AC TAIL 2500)
6. (TYPE-OF-AC TAIL 1500)
7. (PURPOSE-OF-AC 1500 A3)

Now, we pose the query:

GOAL (STORAGE-1 A1 1500 NOSE)

Since the fact already exists in database it returns as true. If we put the query as

GOAL (STORAGE-1 A3 1500 ?TY)

Since no facts match it will try on rules. Here, rule (4) is tried.

```
((STORAGE-1  A3  1500  ?TY) <-
                              (TYPE-OF-AC  ?TY  1500)
                              (PURPOSE-OF-AC  1500  A3))
```

the antecedents become new sub-goals.

SUB-GOAL (TYPE-OF-AC ?TY 1500)

is true and ?TY = TAIL

SUB-GOAL (PURPOSE-OF-AC 1500 A3)

is also true.

The main goal is also true and ?TY = TAIL is returned.

2.3 USER-LEVEL TOOLS OF VIDHI

a. DEFASSERT: is used to add a fact or a rule into the database.

The syntax is as follows:

```
(DEFASRT < NAME > < FORMULA > )
(DEFASSERT < NAME > < CONSEQUENT > < FORMULA 1 > . . .
                                           < FORMULA n > )
```

For example:

```
(DEFASRT  R1  (STORAGE-1  A1  1500  NOSE))
(DEFASRT  R2  (STORAGE-1  ?AA  ?WT  ?TYPE) <-
                            (TYPE-OF-AC  ?TYPE  ?WT)
                            (PURPOSE-OF-AC  ?WT  ?AA))
(UNDEFASSERT < NAME > < FORMULA > ),
```

will remove the above said things from database.

b. ASK-USER: This is a predicate used to interact with the user and pose questions to him and get the response, and store it as facts. The syntax can be represented as follows.

```
(ASK-USER
          (SOURCE < VAR 1 >. . . <VAR m > )
          (TARGET < VAR 1 > . . . <VAR n > )
          (QUESTION   <TEXT>              )
          (TYPES  < TYPE 1 > . . . < TYPE n > ))
```

For the ASK-USER, predicate to be true the following conditions must have to be satisfied,

- All source variables should have values assigned.
- All target variables should be value free.

failure to satisfy either of the above conditions makes ASK-USER fail.

Further details of type specification can be found in VIDHI manual).

Number of answers from the user should be equal to the number of variables in the target and it must satisfy the type specification. After checking the conditions, question is issued and user's response is awaited. An example to illustrate ASK-USER is given below.

```
(ASK-USER (SOURCE  ?WEIGHT)
          (TARGET  ?VELOCITY)
          (QUESTION  What is the stalling velocity of
                     the Airplane)
          (TYPES NUMBER))
```

When ?weight has a value the question is posed with the given text and the user's answer is set to ?velocity as its value, user must respond with a number as declared by the type statement.

c. DEFELABORATION: is used to explain the user, when the user responds with a 'What' to a question.
   A text is stored with the predicate pred to do the above job. The syntax is as follows

   (DEFELAB <pred> (<TEXT>))

d. DEFCOMPUTEPRED: it declares that the predicate is of computational type.

   (DEFCOMP <PRED> LAMBDA EXPRESSION)

Inside the lambda expression computations are done or another function can be called. The values computed can be asserted into database using ASSERTA command.

e. MISCELLANEOUS:
   DEFINTERMEDIATE: to get the intermediate value of that predicate as facts when it was true.

   DSKOUT-SESSION : to store the facts of a particular file in one file

Apart from the above tools, any CLISP functions can be used in VIDHI.

2.4 OPERATIONAL PROCEDURE OF VIDHI

The infer-algorithm in VIDHI takes query and a list as its arguments and does the following operations:

a. It checks to which category the predicate belongs (whether to DEFASRT or DEFCOMPUTE)

b. When it is DEFASRT (i) first it searches in Facts (atomic formulas) under that predicate name and tries for a successful matching. The retrieval is done by 'GET-FACTS' macro. If it fails to get a match in Facts then, (ii) Search is done in rules (formulas - horn clause). When applying rule, the antecedent becomes the new querries. Each one of the sub-goals has to be satisfied just like the original main goal, and the procedure repeats. Macro 'GET-RULES' helps in retrieving. (iii) ASK-USER: This is a special predicate. Here it interacts with the user, putting question and getting proper response. The source variable values and the target variable values are stored under the original predicate name, which calls this ASK-USER predicate as facts. If the user has earlier responded with 'dont know', in that case the question is not repeated any more as the response has been stored under DEFPROP which has a highest priority in search.

c. If the predicate is of computational type, (DEFCOMP) then the functions or predicates are applied to the arguments supplied. And the value returned has to be True or Nil.

Macro,'GET-COMPUTERED' helps in this work.

The features of VIDHI described here have largely been utilised in the present work. Many other features not used or described here may be referred to in the VIDHI Manual.

CHAPTER 3

UNDERCARRIAGE DESIGN DETAILS

3.1 INTRODUCTION

The undercarriage's weight constitutes 3% to 5% of the maximum takeoff weight and 15% to 20% of the structural weight of the aircraft. Though, its contribution to the flying and economy of the aircraft is virtually nothing, when the aircraft is not flying, its function is much more important than any other part of the structure. It may have to perform all or some of the following major functions during the ground-run of the aircraft:

i. As a taxying device; to enable the aircraft to take its takeoff position and to allow it to move away from the runway into the hangers.

ii. At the moment of landing; to change aircraft's direction of motion from a downward sinking to a horizontal run along the runway.

iii. As a braking device; it may have to carry a means of retarding forward motion.

iv. Apart from the above mentioned points, undercarriage absorbs the shocks when taxying over a rough ground. It should not damage the runway or taxiway of aerodrums. It should maintain the stability of aircraft while taxying.

To carryout the above functions, an aircraft undercarriage must possess the following components - tyres, wheels, brakes, shock-absorbers, landing legs and associated retraction equipment.

The aim of preliminary design of undercarriage is to find, the relation between the wheels, and the points of attachment of the gear to the airframe. The type of tyres, bogie arrangements, dimensions of the tyres, and the inflation pressure to be used to avoid runway damages are decided upon in the preliminary design. It is the task of the designer to select the type of braking system to be used, and the type of shock absorber to be adopted in the aircraft. The details of those preliminary design exercises will follow in the present chapter. Basically in this part many of the decisions and the selections have to be made. Whenever a change is made in the parametric design of an aircraft, these decisions and selections may have to be changed based upon the effect of the involved design parameters. An expert system development for this design offers an excellent solution to all these points.

The preliminary design process[8,9] is summarised in the following steps.

3.2 PRELIMINARY DESIGN PROCESS

Here, the design procedure for landplanes with two-leg and three-leg, the wheel carrying elements, are only given.

a. Undercarriages arrangements

The general tendency is to use three-leg elements, two main ones close to the centre of gravity of the aircraft, and an auxillary leg either at the tail as a tailwheel or at the front of the fuselage as a nosewheel. The other type used is two-leg elements, where we have two main load carrying legs placed along the longitudinal axis of the aircraft, both close to its centre of gravity. Two auxillary wheels are located at wing tips to provide stability. Each one of these landing gear arrangements has its own advantages and disadvantages. Depending upon the weight of the aircraft and its purpose of usage, decisions have to be made as to which type to be selected.

i. Tail wheel layout

It has the following advantages:

- A minimum auxillary wheel weight can be achieved when it is located at the rear, quite far off from the aircraft center of gravity.
- It can be located at relatively unimportant part of the fuselage
- Helps in energy dissipation at the time of landing.

It has the following disadvantages:

- Heavy braking can cause over-turning and noise
- Ballooning at the time of landing can be noticed
- Poor pilot's visibility during taxying.

ii. Nosewheel layout

It has the following advantages:

- Inherently stable as the centre of gravity is ahead of the main wheel.
- The floor line of the aircraft is always more or less horizontal.
- It has a short wheel base.

The disadvantages are:

- It is heavier in structure.
- Heavy braking causes skiding.

iii. Bicycle layout

The advantages are:

- Eliminates main leg unit from the wings.
- Good stability is achieved.

The disadvantages are:

- Higher weight.
- Landing is more difficult

b. Disposition of the wheels

The two points that have to be satisfied in fixing the leg units of wheel to aircraft frame are, overturning when the plane is about to land, and stability of aircraft when taxying. At the time of landing it is assumed that the complete weight is acting on the main wheels.

i. Tailwheel type

Mainwheels location:

Here, to avoid overturning an overturning coefficient/O.T.C. has been defined.

$$O.T.C. = F/W \tan\theta$$

Safe value of O.T.C. is 0.8, therefore

$$0.8 = \frac{F}{W \tan\theta}$$

$$0.8 = \frac{f\,W}{W \tan\theta}$$

$$\theta = \tan^{-1}(f/0.8) \quad \ldots \quad (3.1)$$

Where f is the friction coefficient between tyre and ground. Usually θ ranges between 16° and 55°.

The main wheel location can be calculated using

Fore-location $= X_1 = h_{cg} \tan\theta$

The main wheels will be in front of the centre of gravity, along a line from it subtending an angle with the normal to the ground of about θ° and at a distance of 'X_1' from centre of gravity dropped vertically. (Fig. 3.1)

Auxillary wheel location:

Usually the position of auxillary wheel is fixed using the percentage weight it has to carry at the time of taxying. If n% is the carried weight then

$$X_2 = \frac{X_1(100 - n)}{n} \quad \ldots \quad (3.2)$$

gives the rear location. (Fig. 3.1)

Wheel base can be foundout using

$$WB = X_1 + X_2 \qquad \ldots \qquad (3.3)$$

Wheel track can be determined by

$$WT = 2 \times \frac{WB}{X_2} \cot \phi \times h_{cg} \qquad \ldots \qquad (3.3.1)$$

For stability purposes, while taxying maximum ϕ is taken as 60°, lesser the angle more stable the aircraft will be.(Fig.3.1)

ii. Nosewheel type

$$X_1 \geqq (h_{cg} + e_s) \tan \theta_{TD} \qquad \ldots \qquad (3.4)$$

e_s is taken as 0.1 h_{cg} or 6 inches whichever is the lowest.

$$\theta_{TD} = 7 \ (1 + \frac{3}{A}) \qquad \ldots \qquad (3.5)$$

$$X_2 = \frac{X_1(100 - n)}{n} \qquad \ldots \qquad (3.6)$$

Where n is the percentage weight acting on auxillary wheel, which ranges from 8% to 15%.

Wheel base is same as given by equation (3.3) and for wheel track the equation (3.3.1) is applicable.

iii. Bicycle type

The landing gear parameters are given by

$$X_1 = h_{cg} \times \tan \theta \qquad \ldots \qquad (3.7)$$

$$\theta = \tan^{-1} (\frac{F}{W \times 0.8}) \qquad \ldots \qquad (3.8)$$

$$X_2 = \frac{X_1 \ (100 - n)}{n} \qquad \ldots \qquad (3.9)$$

Here the n value is from 50% to 55%. Outriggers are placed at the wing tips.

c. Undercarriage design to airfield bearing capacity

In ordér to avoid damage to runways, airfields specify the bearing capacity of the runways. One of the methods of specification is its LCN, the load classification number. The aircrafts' undercarriage has to be designed for the lowest value of LCN of the airfield from which it has to operate.

The LCN value of the aircraft can be reduced by increasing the number of tyres in leg units and thus reducing the inflation pressure. In Fig. 3.2 graphs have been plotted between Equivalent Single Wheel Load (ESWL) and inflation pressure for different LCN values. Here, the ESWL of a group of two or more wheels which are relatively close together, is equal to the load on an isolated wheel having the same inflation pressure and causing the same stress in the runway material as those due to the group of wheels.

$$\text{ESWL} = \frac{\text{Total load on one undercarriage assembly}}{\text{Reduction factor}}$$

For single wheel, reduction factor is 1.0

For twin wheel assembly, reduction factor is 3/2

For four wheel bogie, reduction factor is 2.0.

Number of wheels in an assembly can be fixed based on load coming on a wheel and the pressure range allowed for the

given LCN value. To bring down the load, number of wheels in that assembly has to be increased. It is preferable to have the inflation pressure as high as possible as it reduces the tyre dimensions and weight. The total wheel load refers to the sum of static and dynamic loads of the aircraft. Total load can also be approximated to

Total load = Factor x static load

The multiplication factor here changes with the weight of aircraft. For light class of aircraft, which weighs less than 12000 lbs, it is taken as 3.0, and it is 2.5 for medium class for which the weight range is specified as 12000-50000 lbs, and for heavy class which weighs 50,000 lbs and above it will be 2.0.

d. Tyre selection

In step c, an approximate pressure has been found. Figures 3.3 and 3.4, give tyre performance data and its dimensions, as quoted by the manufacturers. These figures have been taken from reference 8. The steps to be followed in the tyre selection are:

- The static loads can be found as follows, for main leg 60% of the aircraft weight is taken, for auxillary leg 40% is taken.
- Using the approximate pressure from step c and fig. 3.3-3.4, a tyre can be selected. Sometimes it may not be possible to locate one directly from the pressure and load values. In that case, one with a lower pressure (corresponding to that load) which suits the tyre can be selected. For example,

if the static load is 10,000 lbs and approximate pressure is 65 psi, there is no tyre available for this as the point lies between tyre number 7 and number 8, in that case tyre number 8 should be choosen.

Now, the exact pressure should be calculated moving backwards, that is using static load and the chosen tyre number, pressure can be found from the same graphs. The dimensional details of that tyre is also given by the manufacturer.

e. Wheel flange thickness

Wheel rim diameter is fixed along with the tyre. When a tyre is selected, the manufacturer's specification gives wheel rim diameter. To find the wheel rim flange thickness, the total outwards bursting force is used. The value of which can be calculated by the following emperical relation.[8]

$$F_{TBL} = \pi pr \left(\frac{D^2-d^2}{4r} - (D-r) \right) \quad \ldots \quad (3.10)$$

also we have

$$\frac{F_{TBL}}{\pi dt} = \tau$$

Since the wheels are mostly made up of magnesium alloy castings the τ value can be taken in the range of 9,000-11,000 psi. And, a factor of safety of 1.5 is adopted.

Flange thickness

$$F_{TH} = \frac{1.5 \times F_{TBL}}{\pi d \quad 9000} \quad \ldots \quad (3.11)$$

f. Axle diameter

Axle diameter can be found by the following relation

$$AD^3 = \frac{32.0 \times M}{\pi s} \quad \ldots \quad (3.12)$$

And bending moment M can be calculated

$$M = DL_1 \times \frac{3}{4} \times \text{tyre width}$$

and the allowable design stress

$$s = s_{max}/\text{Factor of safety}$$

the usual values of s_{max} for forged steel may vary between 180,000 and 200,000 psi. If an hallow shaft axle is used, then the above relation modifies to

$$AD_o^3 = \left(\frac{32\ M}{\pi\ s_{max}} \times \frac{1}{1-k^4} \right) \quad \ldots \quad (3.13)$$

$$k = \frac{AD_i}{AD_o}$$

g. Brake design

The main purposes of brakes in aircraft are; to steer the aircraft on the ground, conversion of kinetic energy to heat energy, and dissipation of that heat energy. While designing the brake system for aircraft, care has to be taken to avoid deceleration greater than 10 ft/sec^2, which will cause skidding or over-turning.

The kinetic energy to be absorbed per wheel is given by

$$KE_1 = k\ \frac{WV^2}{2gN} \quad \ldots \quad 3.14)$$

or

$$\text{Energy} = \frac{1}{30} \times \frac{k\, W\, V^2}{N} \quad \ldots \quad (3.15)$$

Where V, the brake application speed in mph.

k - drag loss factor, is 1.0, for nose wheel and 0.7 for tail wheel type.

V is taken as 1.1 times of the stall velocity.

There is a limiting value for the braking force, that can be applied at each wheel to avoid any skidding.

$$\text{Friction-Force at each wheel} = \frac{W}{g} \times \frac{a}{N} = F_1$$

a = maximum deceleration that is allowed.

also $F_1 < fW_1$

If $F_1 > fW_1$ then F_1 is taken as equal to fW_1.

The braking systems can be broadly classified into the following groups.

i. Shoe-type
ii. Drum-type
iii. Disc-type
iv. Parachute-type
v. No brakes at all

i. Shoe brakes

These are used in light aircraft because of its simplycity in operation and low cost of maintenance. The effective braking area and angle of contact can be calculated by the following simple relations.

$$\text{Area of contact of braking material} = \frac{F_1}{p\, f_s} \quad \ldots \quad (3.16)$$

and contact angle

$$\theta_c = \frac{A_c}{2} \quad \frac{1}{t \times R} \quad \ldots \quad (3.17)$$

Where p is shoe pressure, 100-120 psi maximum values

f_s friction coefficient of braking material

t brake lining width in inch

R mean radius of brake shoe

ii. Drum brake

This system is also used only in light aircrafts. Here, the braking efficiency is slightly higher compared to shoe type because of better cooling effect and more area of contact.

iii. Disc brake

It is the most commonly used braking system. Here, frictional surfaces are used normal to the braking force direction thus avoiding the damages on wheel. If there are more than one such surface then it is called as multi-disc brake otherwise single disc brake. The number of discs is decided on the basis of kinetic energy to be absorbed by the system. The number of surfaces needed can be calculated by the following relation

$$n = \frac{3 \times F_1 \times TD}{2\pi f_s p\, (R_o^3 - R_i^3)} \quad \ldots \quad (3.18)$$

Where

TD - tyre diameter

R_o & R_i are outer and inner radii of friction plates

p the disc pressure, varies between 1000 and 1200 psi

F_1 & f_s are same as in the earlier cases.

iv. Parachute braking

Here, a parachute is attached at the rear end of the aircraft and it is opened after landing. This can also be used along with other systems to make braking more effective, as has been done in few fighter aircrafts.

v. No braking device

When there is no restriction on the runway available and if ground friction itself is sufficient to bring the aircraft to halt in reasonable time then braking device can be eliminated. This saves some weight to be carried by the aircraft. The runway needed can be calculated using the relations

$$s = \frac{V^2}{2a} \text{ feet where}$$

$$a = \frac{F_1 \times g}{W}$$

and time to stop after touchdown

$$t = \frac{V}{a} \text{ sec}$$

h. Shock absorbers

A shock absorber in an aircraft performs dual duty of absorbing landing impact energy and providing an elastic suspension when the aircraft taxies.

The main restriction in shock absorber design is that the stroke or shock absorber travel should not be greater than 15 inches and the absorber efficiency should be as high as possible. Several types of shock absorbers are used in aircraft industry, a few of them have been listed below

i. Steel springs

ii. Rubber springs

iii. Pneumatic designs

iv. Oleo-pneumatic designs

v. Liquid-springs, or oil-in-compression types

The one suitable for the present job can be selected by giving some weightage to principle properties of these units like simplicity, weight, efficiency, reliability and recoil damping. The kinetic energy and travel of shock absorber can be calculated using the following relations,

$$\text{Total vertical energy per element} = \frac{W_1 V^2}{2 g} \qquad (3.19)$$

The stroke is calculated using the following equation

$$n\ L\ S = \frac{W\ V^2}{2\ g} \quad \ldots \qquad (3.20)$$

Where L/W can be taken as 3.0.

i. Selectional procedure

In all the preliminary design processes, the major problem is the selection process. Comparison has to be made with alternatives in systematic order to select the better one under the given circumstances. To make the decision easier the alternatives

are rated, and the rating is done based on probability distributions.

Probability distributions are useful where some old data are available. In the present work, Beta distribution has been used as a major criteria in setting up ratings. Beta-probability density function is defined over a range of 0 to 1.0 as

$$f(x) = \frac{(x)^{p-1}\ (1-x)^{q-1}}{B(p,q)} \quad \ldots \qquad (3.21)$$

Where beta-function

$$B(p,q) = \frac{F(p)\ F(q)}{F(p+q)}$$

Where F(p) is gamma function.

and $\quad F(a + k + 1) = a(a + 1)\ (a + 2) \quad \ldots (a + k) \quad F(a) \qquad k=0,1,2 \ldots$

the values of F(a) within the range 1 to 2 can be found from standard tables. By controlling p and q values suitable distribution shapes can be obtained to fit a given data.

The second type of rating is done based on the purpose of aircraft. The aircrafts are classified into 10 groups and depending on the usage, certain rating values has been assigned. The third and last method of rating is, by directly asking the user. Thus the total rating can be found by

Total rating = Rating depending on computed value using Beta-distribution function

+

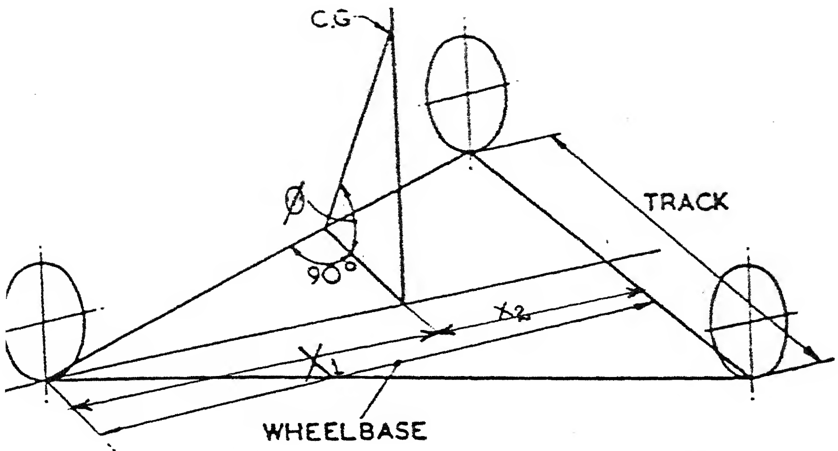
Rating given by the user

+

Rating according to the type of use

The one with the highest total rating value is always chosen for better performance.

The final output of this expert system gives the selections that are made and the design details that were calculated. Also, it gives certain specification details for further design processes of those parts.



The angle ∅ determines the tendency to overturn sideways.

Fig. 3.1 GENERAL ARRANGEMENT OF LEG LOCATIONS

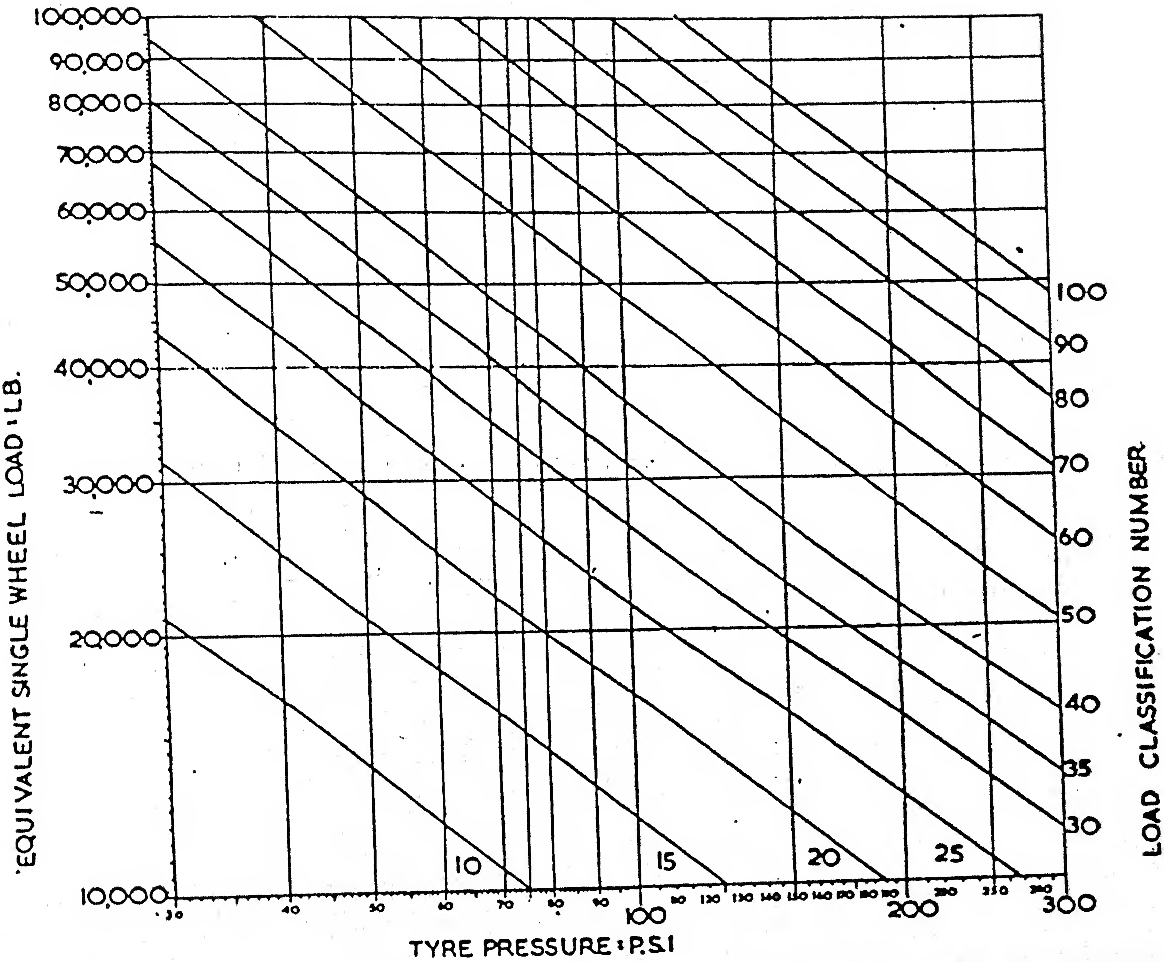
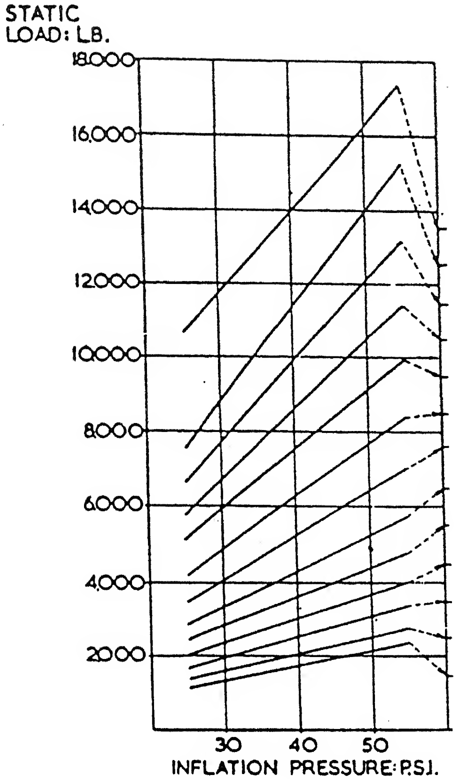
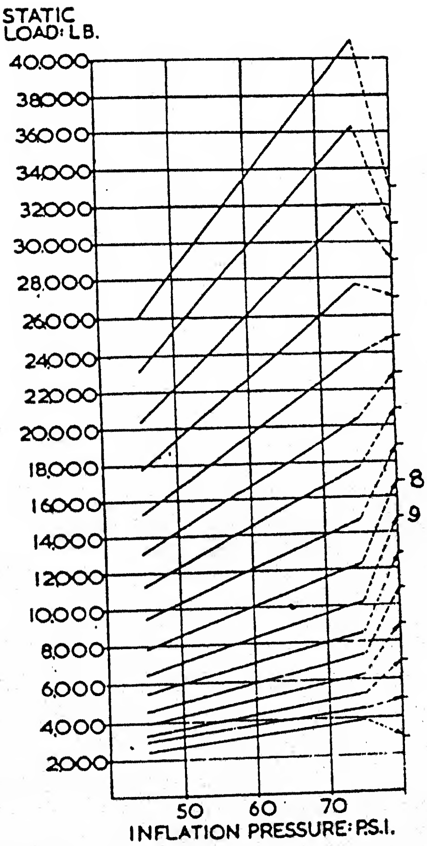


Fig.3.2 Load classification number for various combinations of tyre pressure and wheel load.



Tyre data—tyre range 50 p.s.i. (max.)

Maximum Dimensions (in.) Dia.	Width	*Rim Diameter (in.)*	*Multiplier to obtain maximum dynamic loads*
49·15	18·80	18	2·95
46·3	17·25	17	2·9
43·2	16·1	16	2·9
40·6	15·1	15	2·9
38·3	13·45	15	2·9
35·2	12·35	14	2·9
32·7	10·9	14	2·95
30·2	9·6	13	3·0
27·6	9·1	12	3·0
25·7	8·1	11	3·0
23·6	7·5	10	3·0
21·85	6·95	10	3·0
19·9	6·4	9	3·0

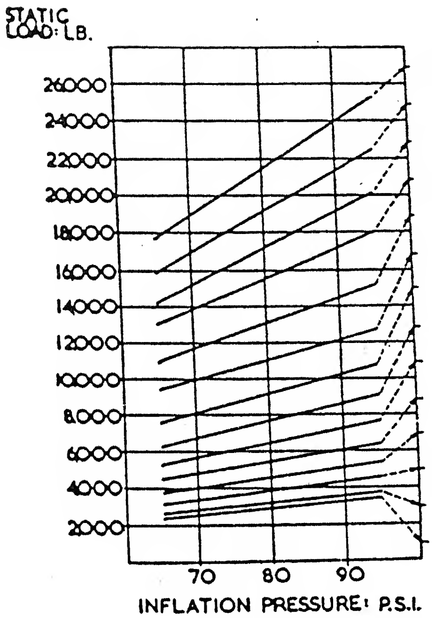


Tyre data—tyre range 70 p.s.i. (max.)

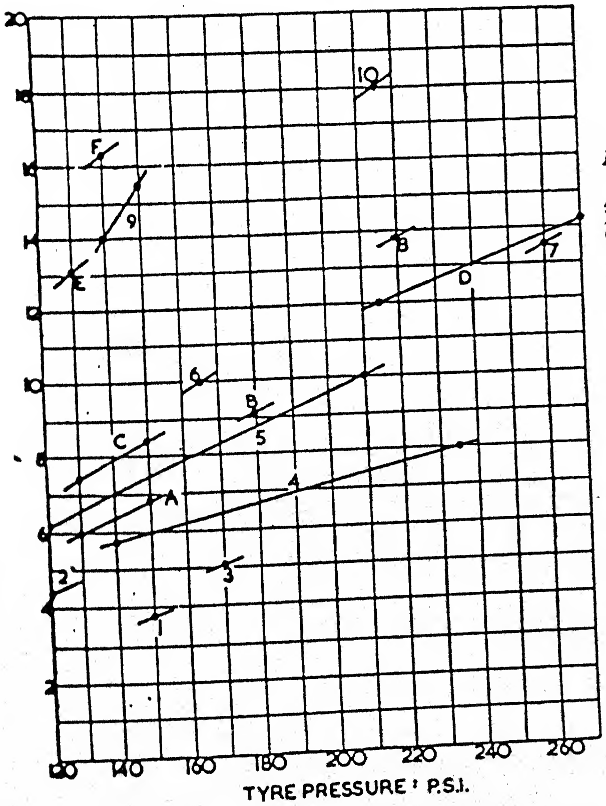
Maximum Dimensions (in.) Dia.	Width	*Rim Diameter (in.)*	*Multiplier to obtain maximum dynamic loads*
65·55	23·3	26	3·05
61·15	21·95	24	2·9
57·9	20·6	23	2·9
53·7	19·15	21	2·9
50·5	17·95	20	2·9
46·5	16·7	18	2·9
43·4	15·6	17	2·9
40·7	13·9	17	2·9
37·6	12·6	16	2·9
35·0	11·2	16	2·9
32·5	10·15	15	2·95
30·7	9·25	15	2·95
28·75	8·5	14	3·0
26·6	8·05	13	3·0
24·85	7·7	12	3·0
22·9	7·0	11	3·0

Fig.3.3 Tyre data I

Tyre data—tyre range 90 p.s.i. (max.)



Maximum Dimensions (in.) Dia.	Maximum Dimensions (in.) Width	Rim Diameter (in.)	Multiplier to obtain maximum dynamic loads
49·2	15·5	21	3·0
46·6	14·65	20	3·0
44·3	13·95	19	3·0
42·0	13·3	18	3·0
38·9	12·15	17	3·05
36·4	11·0	16·5	3·05
34·2	10·05	16	3·1
32·0	9·1	15·5	3·1
30·0	8·25	15	3·0
28·1	7·5	14·5	3·0
26·3	6·85	14	3·0
24·3	6·3	13	3·0
22·6	6·0	12	2·9
20·9	5·55	11	2·9



Tyre data—tyre range above 100 p.s.i.

No.	Maximum Dimensions (in.) Dia.	Maximum Dimensions (in.) Width	Rim Dia.	Multiplier to obtain maximum dynamic load
	BRITISH SIZES			
A	27·5	6·25	15	3·15
B	27·3	6·85	15	2·8
C	30·0	7·00	16	3·0
D	34·0	7·00	20	2·7
E	35·7	9·35	17	3·2
F	36·0	10·50	17	2·9
	AMERICAN SIZES			
1•	20·0	4·50	12	2·9
2	22·0	5·62	12	2·85
3	18·0	5·62	8	2·9
4	24·0	5·62	14	2·8
5	25·75	6·65	14	2·8
6	29·4	7·85	16	2·9
7	32·0	6·45	20	2·8
8	28·4	7·85	15	2·8
9	33·4	10·28	16	2·8
10	33·0	8·90	18	2·8

• British 20·60 × 4·95 — 12 is equivalent.

Other Sizes

British: 44·50 × 13·00 — 21; 24,000 lb. at 135 p.s.i.

American: 45·40 × 8·70 — 30; 22,000 lb. at 240 p.s.i.
43·70 × 13·50 — 20; 35,000 lb. at 200 p.s.i.
56·40 × 16·20 — 28; 45,000 lb. at 178 p.s.i.
60,000 lb. at 240 p.s.i.

Fig. 3.4 Tyre data II

CHAPTER 4

PROGRAM DESCRIPTION AND RULES

4.1 INTRODUCTION

The success of any expert system depends mainly on the quantity and quality of knowledge it has in the domain. As a result it is necessary to modify the knowledge base, with assistance from the user, to update it to the advances in its area of expertise. To do so, the user may have to delete or add a few rules. For this, it is essential for the user to know how the design has been coded, and the structure of the program. The present chapter has been devoted to the above objective. It also describes how to operate the system.

The problem has been divided into three main blocks

- Main frame of the program
- Design details tree
- Alteration tree

Main frame is the central part of the program. It decides which part of the tree has to be actuated according to the users response. The design part of the tree deals with the complete designing of the undercarriage. And the alteration tree part helps in altering the old design according to the users requirement.

4.2 MAIN FRAME OF THE PROGRAM

The main frame gives the outer structure of the program. Fig. 1.2 explains it schematically.

When the user initiates the system with a query, GOAL (START), he enters the top most node in the tree. This makes the program issue questions about two basic inputs, the weight of the aircraft for which the undercarriage has to be designed and for what purpose the aircraft would be used. Here, the purpose of aircrafts has been broadly put in 10 groups to make the design simpler, the groupings are as follows:

i. Agricultural purpose

ii. Light transport 1 to 4 seaters

iii. Trainer 1,2 seaters

iv. Executive transport 4 to 8 seaters

v. Utility aircraft

vi. Light and amateur aircrafts

vii. Fighters

viii. Passengers, air service

ix. Cargo transport

x. Sports planes

With these informations the program starts searching the secondary database for the old design details. This is done by the rule no. 'SR1' which becomes a subquery in process and it is as follows.

```
(DEFASSERT SR1 (KNOWLEDGEBASE-SEARCH  ?AA) <-
                    (WEIGHT-RANGE  ?WT-H  ?WT-L)
                    (STORAGE-PRED3  ?WEIGHT  ?AA  ?D....  ?TY-BR)
                    (< ?WEIGHT  ?WT-H) (> ?WEIGHT  ?WT-L)
                    (OLD-DESIGN-DETAIL-PRED  ?WEIGHT  ?AA  ?D ..?TY-BR
                    (USER-OPINION  ?DUMMY  ?OP  ?DN)
                    (MODIFY-OLD-DESIGN  ?WEIGHT  ?OP  ?DN))
```

All old designs are stored under the predicate name 'STORAGE-PRED3'. Only those designs which have the same purpose as that of the present problem are chosen and the weight of that design is checked to conform whether it lies within the reasonable limit of acceptance. Then that old design is displayed to the user. This is done by the predicate 'OLD-DESIGN-DETAIL-PRED'. Now, the user's opinion is taken giving him the multiple option,

- Retaining the same design
- Altering any one of the designs
- Continuing the search in the database for another design
- Starting altogether a new design

The user's opinion is passed on to the predicate 'MODIFY-OLD-DESIGN' where it is checked. If the user's opinion is to retain the design as it is then it fires a rule which outputs the same result. If the opinion is to alter the design then it fires the alteration tree. For new design, it fires design detail tree causing new design. When the user wishes to continue the

the search then 'MODIFY-OLD-DESIGN', 'USER-OPINION' predicates are made to fail. Now, back tracking takes place and search is continued in 'STORAGE-PRED3' for a next design which satisfies the condition and the same process repeats. After complete search of secondary database the rule SR1 'KNOWLEDGEBASE-SEARCH' fails. Then the second rule with same predicate name is fired, because of backtracking, and this rule will fire the designdetail tree for starting a new design. The second rule 'SR2' is written as follows.

```
(DEFASRT  SR2  (KNOWLEDGEBASE-SEARCH  ?AA) <-
                         (TELL-USER  ?DN)
                         (START-NEW-DESIGN  ?DN))
```

Thus, getting into the system, searching the secondary database and firing one of the rules which affects either a new design or alteration, constitutes the main frame part.

4.3 NEW DESIGN

A complete new design of undercarriage is started when there is no old design available and also when the user wishes to have a new design. The flow chart and the tree structure of the design process is presented in Figures 4.1 to 4.4.

The main frame rule would have initiated the query for the design process rule, which can be written as follows:

```
(DEFASSERT  ND1  (START-NEW-DESIGN  ?DN)<-(AC-WEIGHT  ?WEIGHT)
                                          (CHECK-DECISION  ?WEIGHT)
                                          (DETAIL-DESIGN-OF  ?WEIGHT))
```

The query tree generated for the new design is explained in the following steps in the same order of firing.

a. Type of undercarriage has to be decided first for further design processes. This is done by the rule

```
(DEFASSERT  RS2  (CHECK-DECISION  ?WT)<-(>  ?WT  10000.0)
                                        (NOSEWHEEL-TYPE))
(DEFASSERT  RS3  (CHECK-DECISION  ?WT)<-(PDF))
```

If the weight of the aircraft is greater than 10,000 lbs then the design is done for the nosewheel type or else rating values for all three types of landing gears will be computed.

b. Here the rating value is computed and the maximum rated-one will be selected. The rating is done,

- by finding the probability density function value for all three types
- by giving some weightage to each of them depending on the purpose of the aircraft
- by asking the user to rate them according to his requirement.

Final rating value is the product of all the above three. And, the best rated one is chosen for further design.

c. Leg unit's location calculations are done in this step for the above chosen type of undercarriage. The respective values; height of center of gravity location; percentage weight acting on the auxillary wheel; aspect ratio of the aircraft; and ground friction coefficient; are taken from the user by using ASK-USER predicate, for example for aspect ratio the rule is written as follows

```
(DEFASSERT  NW2  (ASPECT-RATIO  ?WT  ?AS) <-
                              (ASK-USER  (SOURCE  ?WT)
                                         (TARGET  ?AS)
                                         (QUESTION PLEASE SPECIFY THE
                                                   ASPECT-RATIO OF THE
                                                   PLANE)
                                         (TYPES  NUMBER)))
```

These values are used in computing Fore-location, Rear-location, Wheel-base and Wheel-track.

d. The detailed design can be classified as designing of the auxillary leg unit and designing of main leg unit and outputing the complete design. The rule for this is,

```
(DEFASSERT  D1  (DETAIL-DESIGN-OF  ?WT) <-(AC-CLASSIFICATION  ?WT)
                                          (AUX-LEG-UNIT  ?WT)
                                          (MAIN-LEG-UNIT  ?WT)
                                          (STORAGE-PRED1))
```

e. In this step, the dynamic load and static load coming on the leg units are computed. And, the next query for the parts design of the auxillary wheel is generated at the end. The rule is written as follows:

```
(DEFASSERT  D5  (AUX-LEG-UNIT  ?WT) <- (COMPUTE-LOADS-PRED1  ?WT)
                                      (PARTS-DESIGN  AUX-WHEEL))
```

f. The predicate COMPUTE-LOADS-PRED1 is of the computational type which calls a LISP function. Dynamic loads and static load are calculated and they are assigned into the database as another new predicate. The rule is written as follows:

```
(DEFCOMPUTEPRED  COMPUTE-LOADS-PRED  (LAMBDA  (MT  WT  NP)
                 (COMPUTE-LOADS-FUN  WT  NP  MP)  T))
```

g. To complete the design of auxillary wheel parts design has to be done. There is no brake design for auxillary wheel as there will not be any braking device. The parts-design rule can be written as follows:

```
(DEFASSERT  DS1  (PARTS-DESIGN  ?TY) <- (=  ?TY  MAIN-WHEEL)
                                       (DISPLAY-TB11  ?TY)
                                       (AC-WEIGHT  ?WEIGHT)
                                       (LOADS-PRED  ?TY  ?DL  ?SL)
                                       (WHEEL-SELECTION  ?TY  ?DL  ?S
                                       (BRAKE-SELECTION  ?WEIGHT)
                                       (SHOCK-ABSORBER  ?TY  ?WEIGHT)
```

```
(DEFASSERT  DS2  (PARTS-DESIGN  ?TY) <- (DISPLAY-TB11  ?TY)
                                        (AC-WEIGHT  ?WEIGHT)
                                        (LOADS-PRED  ?TY  ?DL  ?SL)
                                        (WHEEL-SELECTION  ?TY ?DL ?SL)
                                        (SHOCK-ABSORBER  ?TY  ?WEIGHT))
```

Rule DS2 is applicable to auxillary wheel parts design and the rule DS1 is used for main wheel parts.

h. This rule is written to design the parts of the main leg-unit.

i. In this step complete wheel design is done, which includes

- Calculating the initial inflation pressure based on the LCN value. The LCN value is decided based on the purpose of usage of the aircraft.
- A suitable tyre will be selected based on the value of initial pressure and the load coming on that wheel.
- Next, the exact pressure to be used for that tyre is calculated which should be less than or equal to the initial pressure.
- Other details like axle diameter and wheel flange thickness are calculated.

The above computations are done for both auxillary-leg wheels and main-leg wheels. The rule used here is

```
(DEFASSERT  D7  (WHEEL-SELECTION  ?TY  ?DL  ?SL) <-
                          (DISPLAY-TB1-WHEEL  ?TY)
                          (PRESSURE-SELECTION  ?TY  ?DL)
                          (TYRE-SELECTION  ?TY  ?SL)
                          (WHEEL-RIM-SELECTION  ?TY  ?SL  ?DL))
```

Here, the information about the LCN, which is given in the Fig. 3.2 has been coded into straight line equations with suitable values of constant so that the data is directly accessible to the program with the help of the user.

Similarly all data about the tyres supplied by the manufacturer has been coded into LISP functions, and a binary search is adopted for the retrieval of the data.

j. This rule is for the shock absorbed selection. The procedure adopted is the same as for selecting the type of undercarriage.

k. This rule calls the parts design rule, now applied to main-leg unit and the design of all parts are same as in the previous case with an extra design of braking system.

l. The sub-query generated at this point is for the complete brake design. Here the kinetic energy to be absorbed by the brake is calculated using the stall velocity of the aircraft. Next the friction force generated between the tyres and the ground is calculated. Rating values of all five types that are stated in section 3.2-g are calculated. Now the rating

values are displayed to the user and his opinion is asked for. The following rules are used in selecting one type of brake system using users opinion.

```
(DEFASRT  BR4  (BRAKE-PRED2-SELE  ?SELECT)<-(=  ?SELECT CON)
                                            (BR-RATING  ?XX)
                                            (BR-SYS-SELE  ?XX))

(DEFASRT  BR5  (BRAKE-PRED2-SELE  ?SELECT)<-(=  ?SELECT  SHOE)
                                            (DESIGN-SHOE-BR))

(DEFASRT  BR6  (BRAKE-PRED2-SELE  ?SELECT)<-(=  ?SELECT  DRUM)
                                            (DESIGN-DRUM-BR))

(DEFASRT  BR7  (BRAKE-PRED2-SELE  ?SELECT)<-(=  ?SELECT  DISC)
                                            (DESIGN-DISC-BR))

(DEFASRT  BR8  (BRAKE-PRED2-SELE  ?SELECT)<-(=  ?SELECT  PARA)
                                            (DESIGN-PARA-BR))

(DEFASRT  BR9  (BRAKE-PRED2-SELE  ?SELECT)<-(DESIGN-NO-BR))
```

After affecting the selection, the corresponding brake system is designed.

m. It is necessary to put all the design details into a file, so that the user can have a hard copy of these details. This predicate has been made to fire at the end of the design process so as to write all the design details into the file the user wishes to have. Whenever it writes into a file immediately the

experience is added into the secondary database by asserting those design details as facts. This part makes the program a learning one.

Once all the above sub-queries becomes true, the predicate START-NEW-DESIGN will also get the truth value and in turn the main query, GOAL(START), will also attain truth value and will come out of the system.

4.4 ALTERATION TREE

This part of the query tree will be generated only when the user wishes to alter any one of the old designs. In the main frame, when the user responds with 'alter' for modification, the predicate 'ALTERATION-PRED1' is fired. Fig. 4.5 and 4.6 explains the alteration tree schematically. The alteration procedure can be broadly divided into the following:

- Finding from the user, whether a particular parameter needs a change, if so what is its new value. While doing so the old value of the parameter is also displayed to help the user in deciding.
- Effects on design, because of the major parameter value change.
- Effects on design, because of the local parameter value change.
- Effect on design, when there is a change in selection. The rule used for this purpose is as follows:

```
(DEFASSERT  AL1  (ALTERATION-PRED1  ?WEIGHT  ? DN)  <-
                 (NEW-VALUES-FIND1  ?WEIGHT  ?DN)
                 (MAJOR-CHANGES  ?WEIGHT  ?DN)
                 (LOCAL-CHANGES  ?WEIGHT  ?DN)
                 (SELECTION-CHANGES  ?WEIGHT  ?DN))
```

a. Finding new values

In this rule all old values of the parameters used for the design, which is to be altered, are retrieved from the database and displayed one by one to the user asking him for his opinion as to whether he likes to effect a change in the parameter value, if so, asking him for the new value. Here the ASK-USER predicate is not used. Instead a CLISP function has been written to perform the above job and the answer are put into database using 'ASSERTA'. When a selection is to be altered, the earlier selection the user opted for will be displayed and new selected type is asserted into the database.

The parameter that the user can change in alteration part are,

- Friction coefficient of tyre and ground
- Percentage weight acting on the auxillary wheel
- Height of centre of gravity
- Aspect ratio of the wing
- Stalling velocity of the aircraft
- Friction coefficient of braking material

- Type of undercarriage
- Type of braking system

The method of incorporating these changes in the design is explained in the following steps.

b. Major changes

When the user alters value of any one or both of the parameters; percentage weight acting on the auxillary leg and the friction coefficient between tyres and ground, a major change in the design is necessary. This is effected by the following rule,

```
(DEFASRT  AL3  (MAJOR-CHANGES  ?WEIGHT  ?DN)  <—
                         (MJ-CH-OPINION  ?OP1  ?OP2)
                         (MJ-CH-%-WT  ?WEIGHT  ?OP1)
                         (MJ-CH-MUE  ?WEIGHT  ?OP2))
```

In this rule first it checks whether the value of the parameter, percentage weight acting on auxillary wheel has changed. If the answer is yes, then it affects changes in complete design, as the loads coming on main-leg and auxillary-leg affects the location calculation, tyre selection, brake and all the other parts. Hence complete redesign is necessary. The following rule achieves this:

```
(DEFASSERT  AL4  (MJ-CH-%-WT  ?WEIGHT  ?OP1) <-
                          (=  ?OP1  YES)
                          (CHANGE-LOCATION-WHEEL  ?OP1)
                          (DETAIL-DESIGN-OF  ?WEIGHT)
                          (CONTROL-PRED2))

(DEFASSERT  AL4A  (MJ-CH-%-WT  ?WEIGHT  ?OP1)   (CONTROL-PRED1-A))
```

The second rule 'AL4A' is used to keep track of redesign process.

The rule 'AL5' explained below is used for the change in friction-coefficient value. Here redesigning of location calculations and redesign of brake system is essential.

```
(DEFASRT  AL5  (MJ-CH-MUE  ?WEIGHT  ?DN) <-
                          (=  OP2  YES)
                          (CONTROL-PRED1-OVER  ?XX)
                          (CHANGE-LOCATION-WHEEL  ?XX)
                          (CONTROL-BR-OVER  ?BR-OP)
                          (CHANGE-IN-BRAKE  ?BR-OP))
```

All redesigns will incorporate all the changed parameter values.

c. Local changes

Changes in the values of some parameters affects only some part of the design. Hence these changes can be easily incorporated by redesigning only that part. Change in height of the centre of gravity or a change in aspect ratio changes only the location of the legs and a few details in location calculation.

Similarly, a change in stall velocity affects only on the redesign of brake. The change in brake friction coefficient affects only brake system.

The rule for these local changes is,

```
(DEFASSERT  AL6  (LOCAL-CHANGES  ?WEIGHT  ?DN)  <-
                              (LOC-CH-OPINION  ?OP3  ?OP4  ?OP5  ?OP6)
                              (CHANGE-HCG  ?OP3)
                              (CHANGE-AS-RATIO  ?OP4)
                              (CHANGE-STALL-VEL  ?OP5)
                              (CHANGE-BR-MUE  ?OP6))
```

A step-by-step check has to be done in all the stages to avoid the repeatation of redesigning of any component. Fig. 4.6 explains the rules schematically.

d. Selection changes

If the user has changed the selection made earlier, redesigning of the corresponding part is essential. In the present problem the user can change his selection in type of undercarriage and brake system. When he changes the undercarriage type, the redesign of location and brake system are necessary. The rule used here is as follows:

```
(DEFASSERT  AL15A  (TYPE-LAND-GEAR-CHANGE  ?WEIGHT  ?OP7)  <-
                   (=  ?OP7  YES)
                   (CONTROL-PRED1-OVER  ?XX)
                   (CHANGE-LOCATION-WHEEL  ?XX)
                   (CONTROL-BR-OVER  ?YY)
                   (CHANGE*IN-BRAKE  ?YY))
```

For change in brake system, only brake design recalculation is necessary. The rule used is:

```
(DEFASSERT  AL16A  (BRAKE-SYSTEM-CHANGE  ?WEIGHT  ?OP8)
                   (=  ?OP8  YES)
                   (CONTROL-BR-OVER  ?XX)
                   (CHANGE-IN-BRAKE  ?XX))
```

After complete redesigning is over, the results are output into a file and the new design is stored as 'experience'.

4.4.1 It is essential to mention here that the flexibility provided in the present program is not of the general type. Here, the effects of the parameter changes are identified manually and then corresponding actions have been taken. It serves the problem under study. If the program can identify the effect and generate suitable rules on its own, it would have been a more general program. In the present work it has not been achieved.

4.5 PROGRAM OPERATION SCHEME

The system is highly interactive. It informs the user about the position of the design and the values it has computed.

The user is also expected to answer some very essential questions, and a few other questions that he can answer by following the system instructions.

To activate the program the user has to type

(GOAL (START))

Now the system takes charge of the proceedings and puts forth the questions. It is helpful if the user knows what are all the values that he has to supply to the program before hand. The following are the list of values expected from the user along with some useful tips.

A. Weight of the aircraft

The value can range from 500 lb to 100,000 lb.

B. The purpose for which the aircraft will be used

The classification list will be displayed and the user is expected to respond with a code as instructed.

C. Modification tree

Here, the user is expected to answer more than one question and the direction and instruction are displayed.

D. Design parameter values

- Height of centre of gravity

  There is no option for this. The designer is expected to know this value, which should be in feet.

- Weight distribution between the leg units

  This is usually mentioned as percentage weight acting on auxillary wheel. Usual values are for tailwheel type. 8% to 12%, for nosewheel type 10% to 15%. Default optional value taken by the program is 10%.

- Wing aspect ratio

  There is no option and designer is expected to know the answer, and it should be in sq.ft.

- Friction coefficient between tyre and ground

  Usual value ranges from 0.25 to 0.8. Optional value taken by the system is 0.7.

- Stall velocity of the aircraft

  This is a design parameter and no option is available.

E. Selection and opinions

- Type of undercarriage

  Here, he has to rate all three types according to his requirement. The values should be between 0 and 1. Optional values taken will be 0.3 for all three types.

- Brake selection

  Here the user has to just type as indicated by the program.

- Design number

  User can give any design number and the design is stored under that name.

If the user fails to answer the questions where there is no option by saying 'Don't know', the system fails to give any answer and gives an error message.

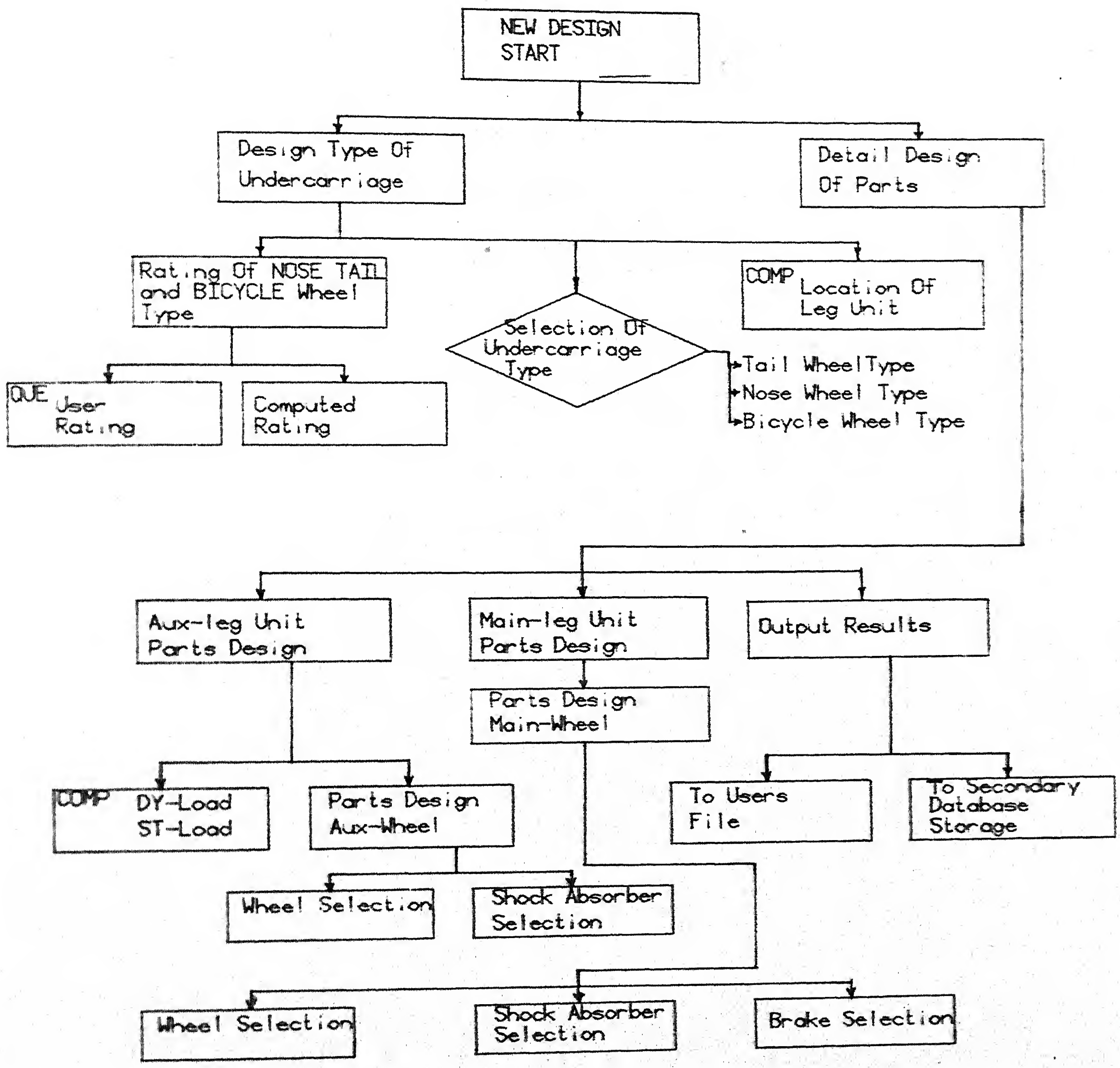


Fig. 4.1 Flow Chart For Main Design

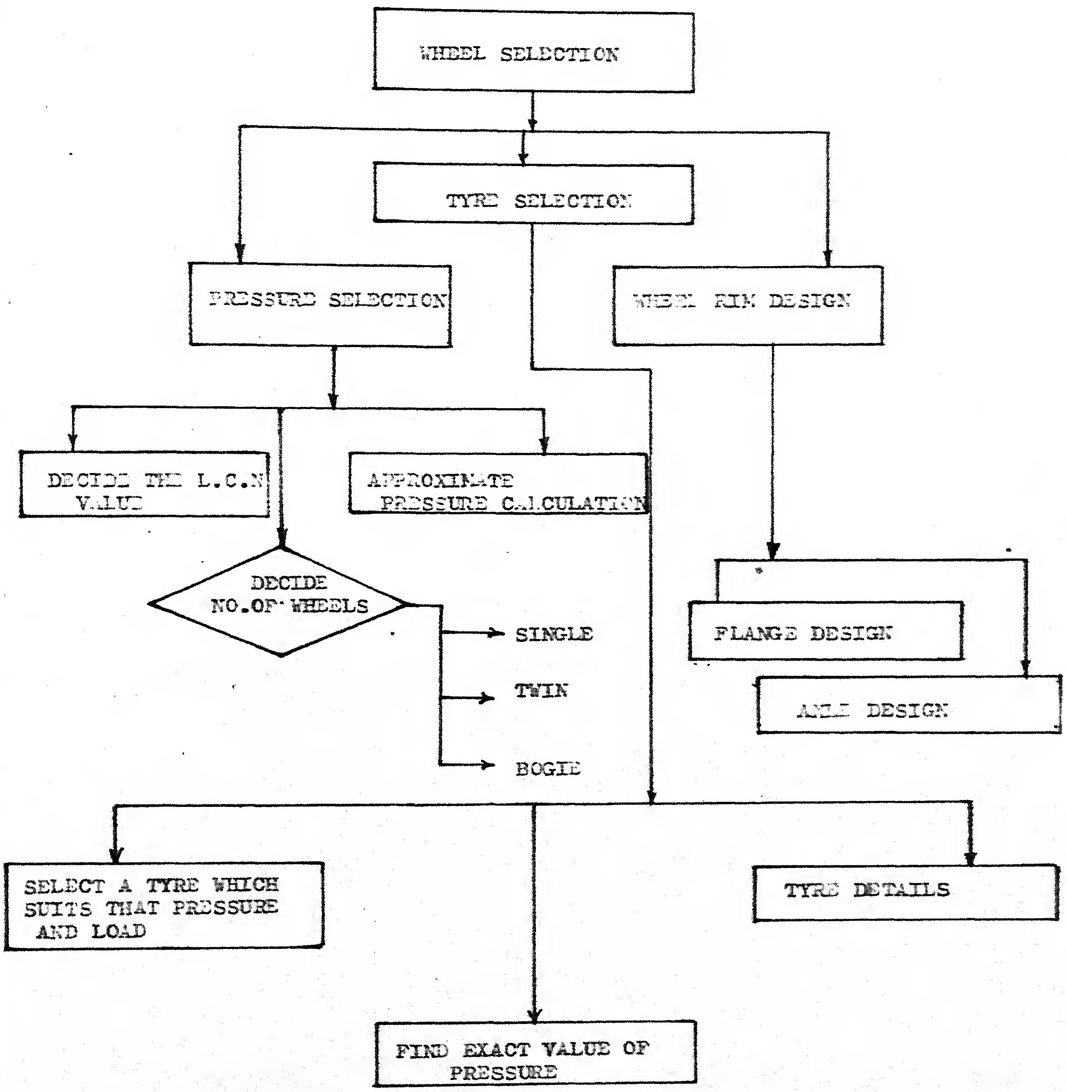


Fig. 4.2 FLOW CHART FOR WHEEL DESIGN

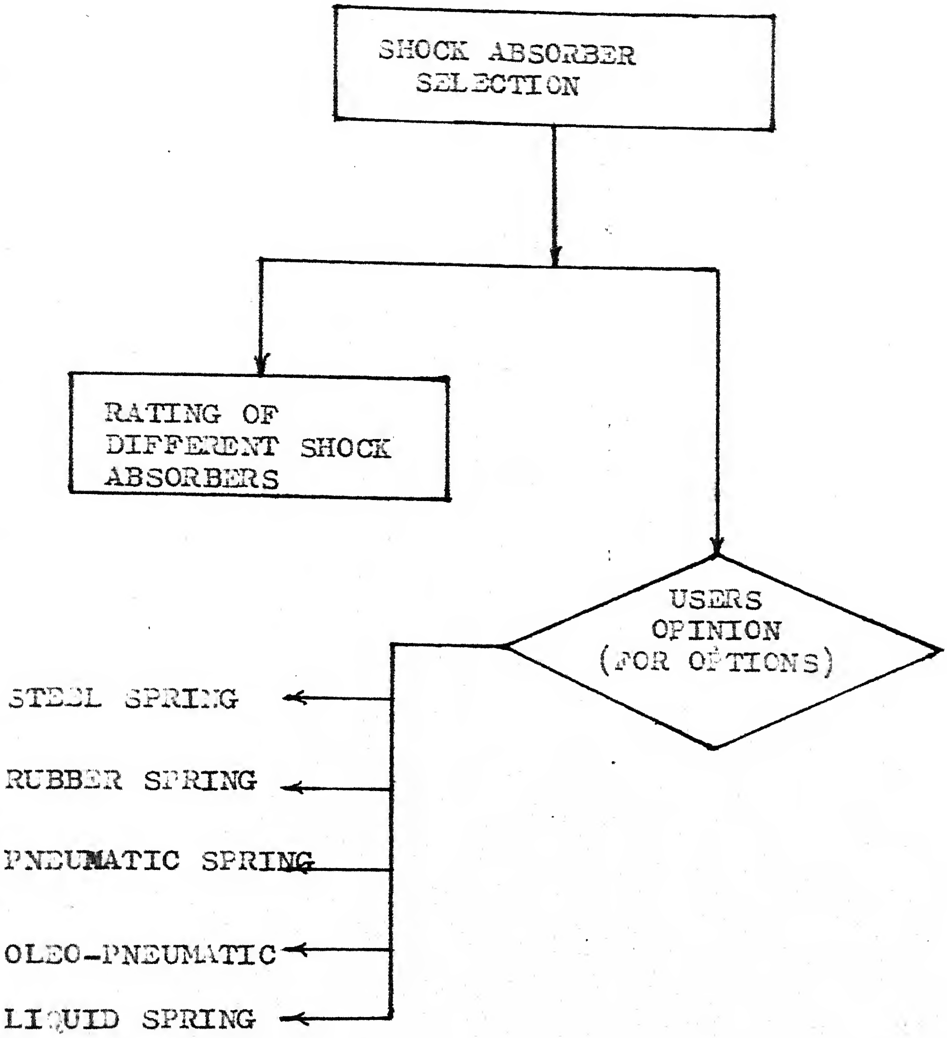


Fig. 4.3 FLOWCHART FOR SHOCK ABSORBER

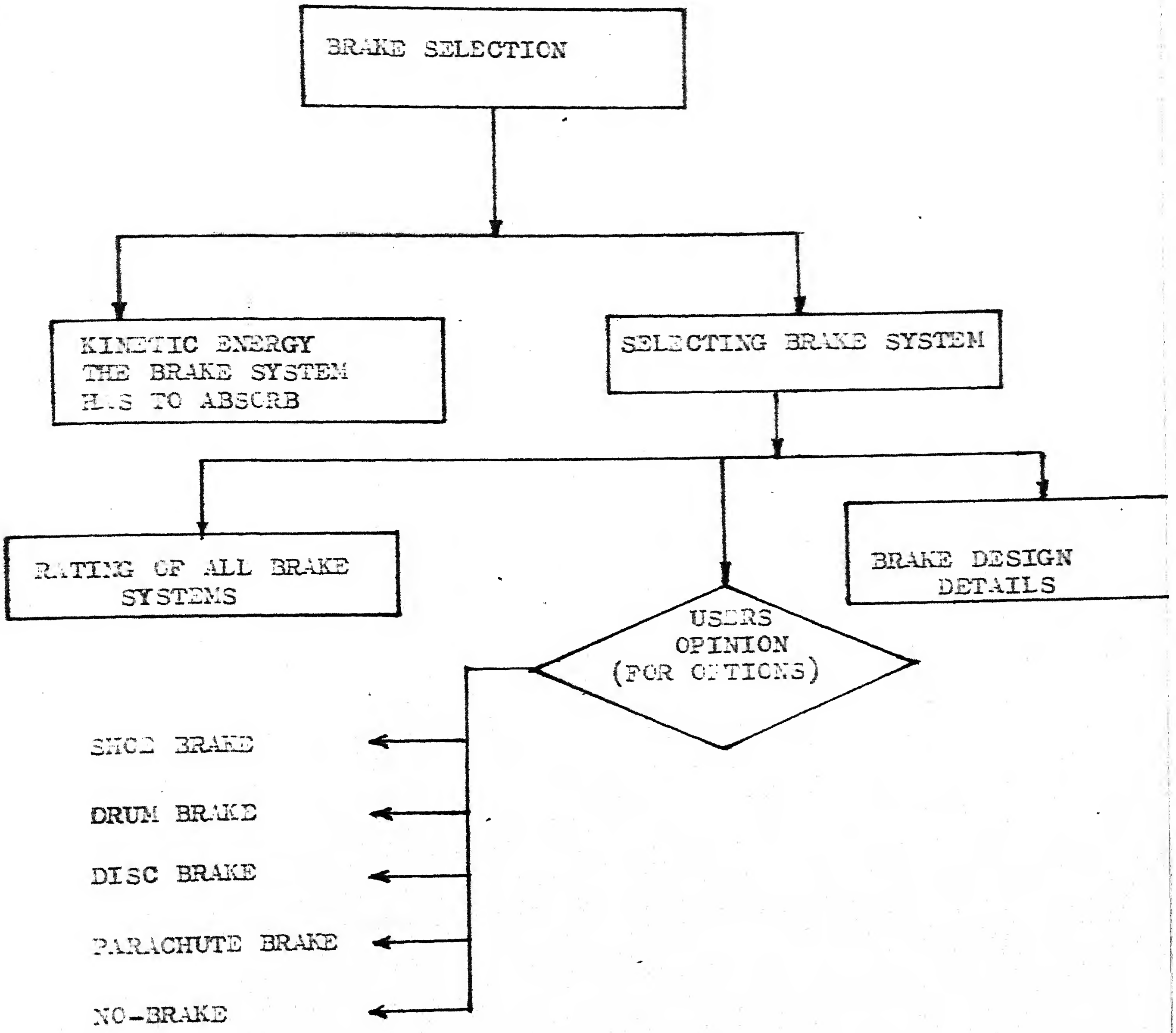


Fig. 4.4 FLOWCHART FOR BRAKE DESIGN

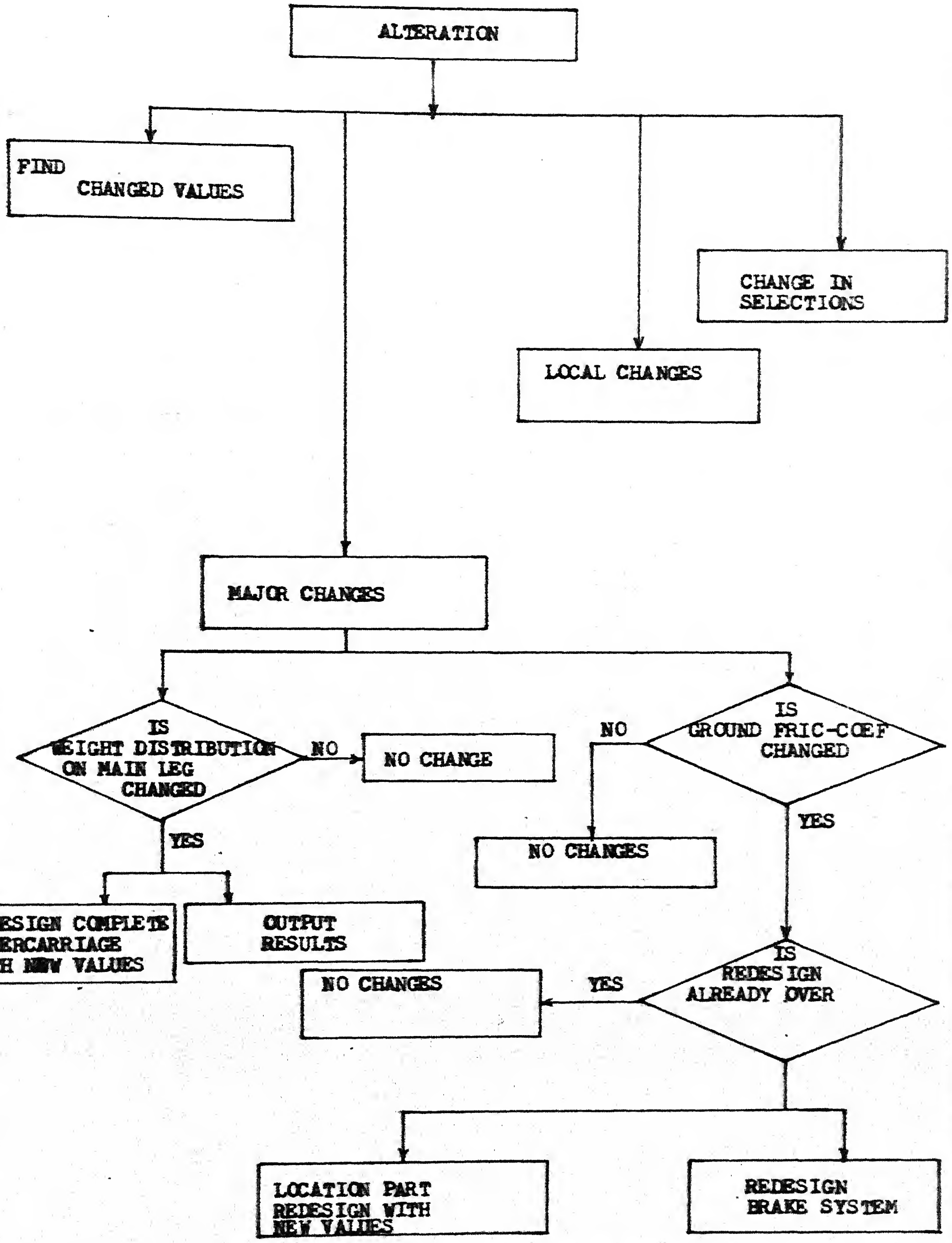


Fig.4.5 FLOW CHART FOR ALTERATION TREE-1

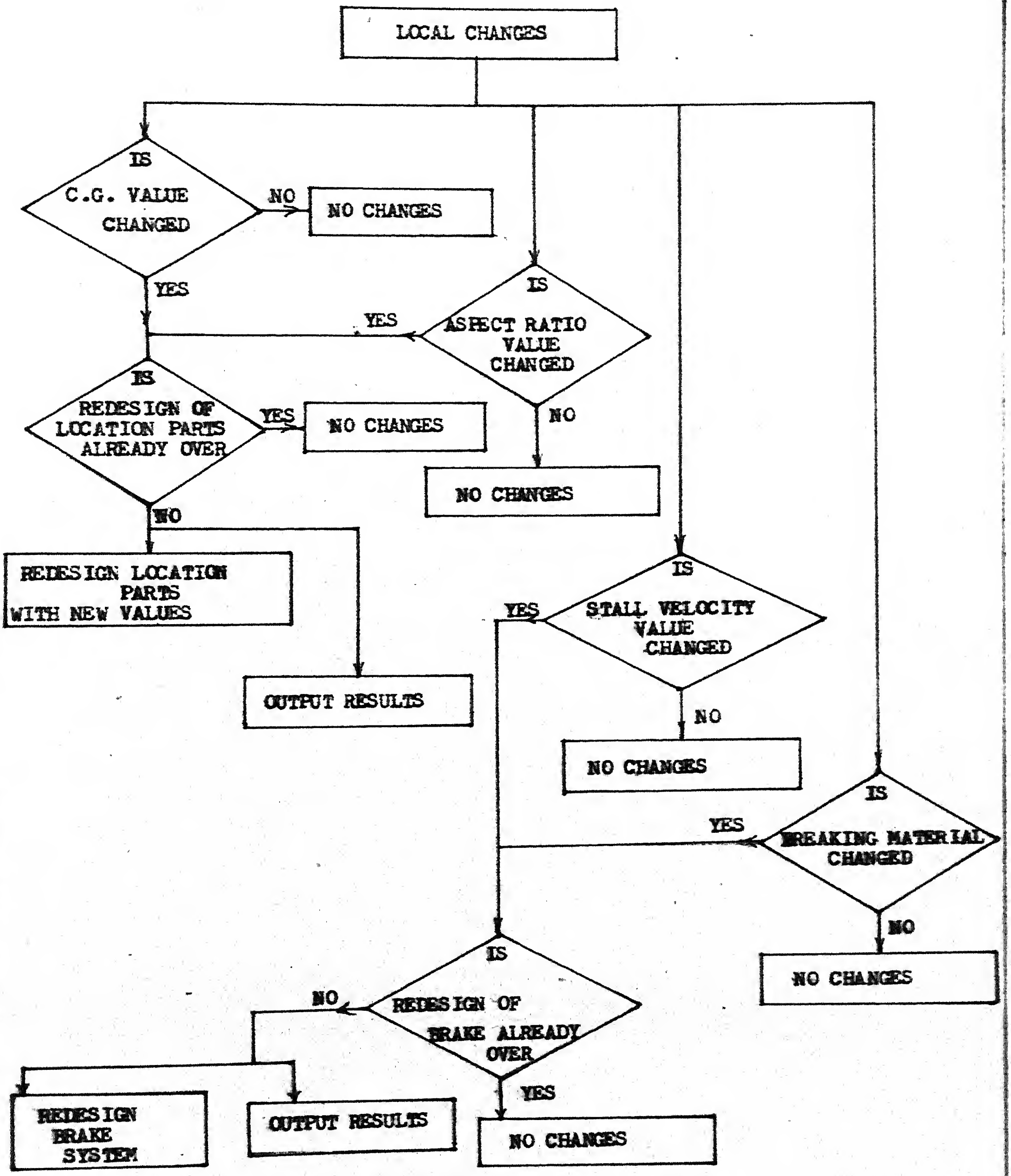


Fig. 4.6 FLOW CHART FOR ALTERATION TREE-2

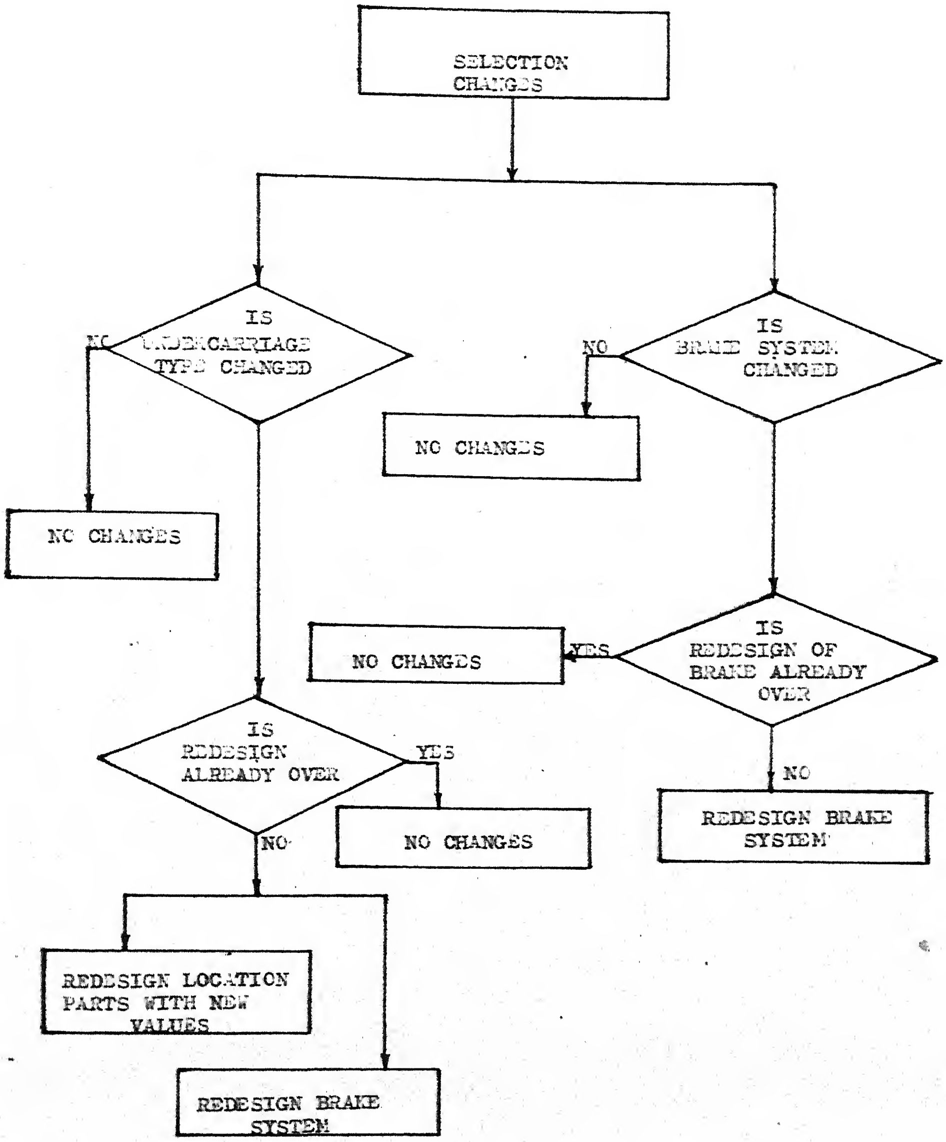


Fig. 4.7 FLOW CHART FOR ALTERATION TREE-3

CHAPTER 5

DISCUSSION AND CONCLUSION

5.1 INTRODUCTION

For a proper understanding of the use and capabilities of the programme package it is essential to run the system for solution of some general examples. In this chapter discussions are presented on the results that are obtained by solving a few representative problems using the system.

5.2 DISCUSSION OF RESULTS

The following six sample runs have been chosen to illustrate and discuss the main features and working of the program.

a. Sample One-New design

This is selected to show the complete behaviour of the program when it solves a new problem for which there does not exist any old design. Here, the expert system putsforth the questions as and when the values are required. A very light weight aircraft is selected, where it is possible to have nosewheel type or talewheel type of undercarriage. The details about the system's questions and explanations, the corresponding response of the user, and the details of design as it has been written into the output file, can be found in the record file. (placed in Appendix).

b. Sample Two-Design and existing in the data base

When there is a change in the weight of the aircraft and purpose of the aircraft, compared to sample one, the system behaves in a different way. The output of the system is also different. In this sample a light plane of nosewheel type is solved. The complete record file is attached in Appendix.

c. Sample Three-A design existing in the data base,new design option

The weight of the aircraft and its purpose is same as that of the example two. The system responds with displaying old design details, as the design has been already done. Here, the response given by the user is to start a new design. The system designs the complete undercarriage. But most of the questions are not asked here. The system's behaviour is similar to that of sample two, only difference being in less number of questions. The design details are similar to sample two. Thus, it proves the system is consistant for consistant response from the user.

d. Sample Four-Design in the data base, old design opted for

The problem is same as that of sample two. Here the data base is searched and the user selected to retain the same old design. No ddsign is done and the output is copied from the database as it is into an output file.

e. Sample Five-Design in the database, local alteration option

For comparison purposes the same as earlier example input, weight and purpose of the aircraft are given in this sample also. After searching the database the user has responded to alter one of the designs. In this case the system responds with new set of questions, as can be found in the record file. The user likes to change the value of height of the centre of gravity. Since it is a local change, it can be noticed that, only redesigning of location part is done. The difference in the location calculation values can be noticed from the detail design. The record file of this sample run can be found in Appendix.

f. Sample Six-Design in the database, major alteration option

The example is same as that of five. Here also the user wishes to alter an old design. More number of changes are made in the parameters and as a result the complete undercarriage has been redesigned. Record file six, in the Appendix, gives the details of proceedings.

5.3 CONCLUSION

An expert system for the design of aircraft undercarriage has been developed. The system has high degree of flexibility and gains 'experience' in each run. It is user friendly while extracting information from him. It gives suggestions and aids him in taking decisions. If the user has difficulty in deciding, he can ask the

system to take decisions. In that case it takes reasonable decision and informs the user. It explains the design process. It may be used as a teaching aid for beginner and effective tool for an experienced designer. It can also be used as a sub-system by attaching to another main system.

The design procedure details of the undercarriage has been worked out for some components of the undercarriage. These include the tyre design, wheel design, brake design. The selections made in the process include type of landing gear, tyre pressure, tyre size, brake system type and shock absorber.

The complete design has been coded into 'if-then' rules in the knowledgebase.

After running this expert system for many number of times, it should be possible to get a detail design for any type of problem without designing the undercarriage compbetely, i.e. just by modifying some part of the undercarriage design.

5.4 SUGGESTIONS FOR FURTHER DEVELOPMENTS

The design details of other mechanism in the undercarriage, like retraction type and retraction mechanism, shock absorber fixing arrangements, the detail of mechanical parts of the shock absorber etc. can be coded into the database. Thus making the design more complete. Also advanced designs, if and when available for the

parts that has been already coded, can be added to the knowledgebase from time to time.

The weight optimization and stress analysis for important members of undercarriage can be incorporated to generate an optimal solution.

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```
RECORD FILE DSK: SESS6 OPENED 19-MAR-87 22:35:48
NIL
<11>(GOAL (START))
(QUESTION PLEASE SPECIFY THE WEIGHT OF THE AIRCRAFT IN POUNDS) >8930
=====================================================================
1 AGRICULTURAL PURPOSE                                  TYPE  A1
2 LIGHT TRANSPORT 1 2 3 4 SEATER     TYPE A2
3 TRAINER 1 2 SEATER                                    TYPE A3
4 EXECUTIVE TRANSPORT 4-8 SEATER     TYPE A4
5 UTILITY AIRCRAFT                   TYPE A5
6 LIGHT,AMETURE A/C                                     TYPE A6
7 FIGHTERS                           TYPE A7
8 PASSANGER,AIRSERVICE                                  TYPE A8
9 CARGO TRANSPORT                    TYPE A9
10 SPORTS PLANES                     TYPE A10
=====================================================================
(QUESTION PLEASE SELECT FROM THE ABOVE TABLE AND ANSWER) >A5
=====================================================================
          OLD DESIGN DETAIL
=====================================================================
     DESIGN NO =                ND3
     PURPOSE OF THE A/C                  A5
     WEIGHT OF THIS A/C  =                8930
LANDING GEAR TYPE     PN
---------------------------------------------------------------------
LOCATION DETAIL ...
          WHEEL BASE = 7.8345134                     WHEEL TRACK = 5.90625
---------------------------------------------------------------------
          AUX-WHEEL DETAIL
          ..................
     PRESSURE   = 101.66666  psi            TYRE DIA = 18.0  inchs
      TYRE WIDTH = 5.6200000  inchs                      RIM DIA = 8.0
     AXEL DIA = 1.1529230 WHEEL FLANGE THICKNESS = 0.11374851
---------------------------------------------------------------------
          MAIN WHEEL DETAIL
          ........................
     PRESSURE = 111.46000   psi            TYRE DIA = 29.400000  inchs
      TYRE WIDTH = 7.8500000  inchs                      RIM DIA = 16.0
     AXLE DIA = 2.6052719  inchs        WHEEL FLANGE THICKNESS = 0.85178170E-1
---------------------------------------------------------------------
          TYPE OF BRAKING SYSTEM......   DISC
=====================================================================
TYPE   CON      FOR CONTINUE >CON
  TYPE THE OPTION AS INDICATED   BELOW
---------------------------------------------------------------------
           OPTION                     SHORT FORM TO BE TYPED
---------------------------------------------------------------------

     DESIGN COMPLETELY ACCEPTABLE                  OK  <THAT DESIGN NO>

DESIGN ACCEPTABLE AFTER ALTERATION              ALTER   <THAT DESIGN NO >
     FURTHER SEARCH DESIRED                    SEARCH < XX >
     A NEW DESIGN DESIRED                      NEW   <NEW DESIGN NO>
=====================================================================
(QUESTION PLEASE TYPE YOUR OPINION NOW) >ALTER ND3
```

```
RECORD FILE DSK: SES56 OPENED 19-MAR-87 22:35:48
NIL
<11>(GOAL (START))
(QUESTION PLEASE SPECIFY THE WEIGHT OF THE AIRCRAFT IN POUNDS) >8930
====================================================================
1 AGRICULTURAL PURPOSE                                TYPE  A1
2 LIGHT TRANSPORT 1 2 3 4 SEATER          TYPE A2
3 TRAINER 1 2 SEATER                                  TYPE A3
4 EXECUTIVE TRANSPORT 4-8 SEATER          TYPE A4
5 UTILITY AIRCRAFT                        TYPE A5
6 LIGHT,AMETURE A/C                                   TYPE A6
7 FIGHTERS                                TYPE A7
8 PASSANGER,AIRSERVICE                                TYPE A8
9 CARGO TRANSPORT                         TYPE A9
10 SPORTS PLANES                          TYPE A10
==========================================================================
(QUESTION PLEASE SELECT FROM THE ABOVE TABLE AND ANSWER) >A5
===================================================================================
          OLD DESIGN DETAIL
===================================================================================
      DESIGN NO =             NO3
      PURPOSE OF THE A/C                  A5
      WEIGHT OF THIS A/C  =               8930
LANDING GEAR TYPE      PN
-------------------------------------------------------------------------------
LOCATION DETAIL ...
          WHEEL BASE = 7.8345134                      WHEEL TRACK = 5.90625
-------------------------------------------------------------------------
          AUX-WHEEL DETAIL
          ..................
      PRESSURE  = 101.66666  psi               TYRE DIA = 18.0  inchs
       TYRE WIDTH = 5.6200000  inchs                          RIM DIA = 8.0
      AXEL DIA = 1.1529230 WHEEL FLANGE THICKNESS = 0.11374351
-------------------------------------------------------------------------
          MAIN WHEEL DETAIL
          ........................
      PRESSURE = 111.46000   psi               TYRE DIA = 29.400000  inchs
       TYRE WIDTH = 7.8500000  inchs                          RIM DIA = 16.0
      AXLE DIA = 2.5052710  inchs         WHEEL FLANGE THICKNESS = 0.85178170E-1
-----------------------------------------------------------------------------
          TYPE OF BRAKING SYSTEM......   DISC
=============================================================================
TYPE   CON      FOR CONTINUE >CON
 TYPE THE OPTION AS INDICATED   BELOW
-----------------------------------------------------------------------------
           OPTION                         SHORT FORM TO BE TYPED
--------------------------------------------------------------------------------
*
      DESIGN COMPLETELY ACCEPTABLE                     OK  <THAT DESIGN NO>

DESIGN ACCEPTABLE AFTER ALTERATION                ALTER   <THAT DESIGN NO >
      FURTHER SEARCH DESIRED                    SEARCH < XX >
      A NEW DESIGN DESIRED                      NEW   <NEW DESIGN NO>
=============================================================================
(QUESTION PLEASE TYPE YOUR OPINION NOW) >ALTER NO3
```

```
PLEASE TYPE A NEW DESIGN NO ............................>NO6
OLD DESIGN PARAMETERS ARE LISTED BELOW . GIVE OPENION BY TYPING   change  OR
 no
--------------------------------------------------------------------------------------
        name of the parameter                old value              opinion/newvalue
--------------------------------------------------------------------------------------
        FRICTION-COEF  GROUND                        0.64999999                >NO
        % WEIGHT ACTING ON AUX-WHEEL               12.0                  >NO
          CG VALUE OF THE A/C                        4.5                   >CHANGE
  PLEASE TYPE NEW VALUE OF CG ....                 >5.25
          ASPECT-RATIO VALUE                         5.6000000                  >NO
        STALLING VELOCITY OF A/C                   103.0                >NO
       FRICTION-COEF OF BRAKING MATERIAL                0.75                  >NO
       TYPE OF LANDING GEAR                  PN              >NO
          BRAKING SYSTEM                     DISC                >NO
.......................................................
DESIGN WILL BE DONE FOR NOSEWHEEL-TYPE
.............................................
-------------------------------------------------------
       UNDERCARRIAGE LOCATION DETAILS
FORE LOCATION                       1.0964118  feet
AFT LOCATION                        8.0403538  feet
WHEEL BASE                          9.1367658  feet
WHEEL TRACK                         6.890625  feet
-------------------------------------------------------
 DOING LOCATION CALCULATION
YES
Should I try for anotner answer (Y/N):>N
```

```
<12>TY RESULT
=================================================================
     DESIGN DETAIL OF UNDER CARRIAGE
=================================================================
     DESIGN NUMBER ----------  ND6
-----------------------------------------------------------------
      PURPOSE OF THE AIRCRAFT -----  A5
-----------------------------------------------------------------
     WEIGHT OF THE A/C -----  8930
     TYPE OF LANDING GEAR ----  PN
-----------------------------------------------------------------
     LOCATION DETAILS
-----------------------------------------------------------------
     WHEEL BASE ------  9.1367658
     WHEEL TRACK -----  6.890525
=================================================================
      AUXLLARY LEG UNIT DETAIL ......
=================================================================
      AUX-WHEEL PRESSURE --- 101.66666  psi
      TYRE DIAMETER  ---- 18.0  inch
      TYRE WIDTH ----      5.6200000 inch
      RIM DIAMETER -----  8.0 inch
      AXLE DIAMETER ---- 1.1529230 incn
      RIM FLANGE THICKNESS -- 0.11374864 incn
=================================================================
          MAIN LEG UNIT DETAILS .....
=================================================================
      MAIN WHEEL PRESSURE ---- 111.46000  psi
      TYRE DIAMETER ----  29.400000   inch
      TYRE WIDTH ----  7.8500000  inch
      RIM DIA OF THE MAIN WHEEL ----  16.0 incns
      AXLE DIA OF THE MAIN WHEEL ----  2.5052710 incns
      FLANGE THICKNESS OF THE RIM ----0.85178170E-1  incns
-----------------------------------------------------------------
      TYPE OF THE BRAKEING SYSTEM ---  DISC ---
=================================================================
      SHOCK ABSORBER
      MAIN WHEEL            OLEO-PNUEMATIC
     AUXILLARY WHEEL PNUEMATIC
=================================================================
               ......END OF DETAILS .....
=================================================================
NIL
$EOF$
<13>RECORDFILE
RECORD FILE DSK: SESS6 CLOSED 19-MAR-87 22:38:34
```

```
RECORD FILE DSK: SESS6 OPENED 19-MAR-87 22:35:48
NIL
<11>(GOAL (START))
(QUESTION PLEASE SPECIFY THE WEIGHT OF THE AIRCRAFT IN POUNDS) >8930
================================================================
1 AGRICULTURAL PURPOSE                          TYPE  A1
2 LIGHT TRANSPORT 1 2 3 4 SEATER       TYPE A2
3 TRAINER 1 2 SEATER                            TYPE A3
4 EXECUTIVE TRANSPORT 4-8 SEATER       TYPE A4
5 UTILITY AIRCRAFT                       TYPE A5
6 LIGHT,AMETURE A/C                             TYPE A6
7 FIGHTERS                               TYPE A7
8 PASSANGER,AIRSERVICE                          TYPE A8
9 CARGO TRANSPORT                        TYPE A9
10 SPORTS PLANES                         TYPE A10
======================================================================
(QUESTION PLEASE SELECT FROM THE ABOVE TABLE AND ANSWER) >A5
==================================================================================
          OLD DESIGN DETAIL
==================================================================================
     DESIGN NO =              NO3
     PURPOSE OF THE A/C              A5
     WEIGHT OF THIS A/C  =            8930
LANDING GEAR TYPE     PN
--------------------------------------------------------------------------------
LOCATION DETAIL ...
          WHEEL BASE = 7.8315134               WHEEL TRACK = 5.90625
--------------------------------------------------------------------------------
          AUX-WHEEL DETAIL
          ....................
     PRESSURE  = 101.66666   psi           TYRE DIA = 18.0  inchs
      TYRE WIDTH = 5.6200000  inchs                     RIM DIA = 8.0
     AXEL DIA = 1.1529230 WHEEL FLANGE THICKNESS = 0.11374854
--------------------------------------------------------------------------------
          MAIN WHEEL DETAIL
          .......................
     PRESSURE = 111.46000   psi           TYRE DIA = 29.400000  inchs
      TYRE WIDTH = 7.8500000  inchs                     RIM DIA = 16.0
     AXLE DIA = 2.5052710  inchs      WHEEL FLANGE THICKNESS = 0.85178170E-1
--------------------------------------------------------------------------------
          TYPE OF BRAKING SYSTEM......   DISC
================================================================================
TYPE   CON     FOR CONTINUE >CON
  TYPE THE OPTION AS INDICATED   BELOW
--------------------------------------------------------------------------------
          OPTION                      SHORT FORM TO BE TYPED
---------------------------------------------------------------------------------
-
     DESIGN COMPLETELY ACCEPTABLE                    OK  <THAT DESIGN NO>

DESIGN ACCEPTABLE AFTER ALTERATION                ALTER   <THAT DESIGN NO >
     FURTHER SEARCH DESIRED                     SEARCH < XX >
     A NEW DESIGN DESIRED                       NEW   <NEW DESIGN NO>
================================================================================
(QUESTION PLEASE TYPE YOUR OPINION NOW) >ALTER NO3
```

```
PLEASE TYPE A NEW DESIGN NO ..................>NO6
OLD DESIGN PARAMETERS ARE LISTED BELOW : GIVE OPENION BY TYPING   change  OR
 no
------------------------------------------------------------------------------------
        name of the parameter                     old value            opinion/newvalue
------------------------------------------------------------------------------------
      FRICTION-COEF  GROUND                            0.64999999              >NO
       % WEIGHT ACTING ON AUX-WHEEL                   12.0              >NO
        CG VALUE OF THE A/C                             4.5              >CHANGE
 PLEASE TYPE NEW VALUE OF CG ....               >5.25
        ASPECT-RATIO VALUE                             5.6000000               >NO
      STALLING VELOCITY OF A/C                  103.0                  >NO
     FRICTION-COEF OF BRAKING MATERIAL                  0.75               >NO
     TYPE OF LANDING GEAR                  PN                >NO
        BRAKING SYSTEM                     DISC                 >NO
.....................................................
DESIGN WILL BE DONE FOR NOSEWHEEL-TYPE
...........................................
-----------------------------------------------------
     UNDERCARRIAGE LOCATION DETAILS
FORE LOCATION                       1.0964118   feet
AFT LOCATION                        8.0403538   feet
WHEEL BASE                          9.1367658   feet
WHEEL TRACK                         6.890625   feet
------------------------------------------------------
 DOING LOCATION CALCULATION
YES
Should I try for another answer (Y/N):>N
```

```
<12>TY RESULT
=====================================================================
     DESIGN DETAIL OF UNDER CARRIAGE
=====================================================================
     DESIGN NUMBER ------------ ND6
---------------------------------------------------------------------
      PURPOSE OF THE AIRCRAFT ----- A5
---------------------------------------------------------------------
     WEIGHT OF THE A/C ----- 8930
     TYPE OF LANDING GEAR ---- PN
---------------------------------------------------------------------
     LOCATION DETAILS
---------------------------------------------------------------------
     WHEEL BASE ------ 9.1367658
     WHEEL TRACK ----- 6.390525
=====================================================================
      AUXLLARY LEG UNIT DETAIL ......
=====================================================================
      AUX-WHEEL PRESSURE --- 101.66666  psi
      TYRE DIAMETER  ---- 18.0  inch
      TYRE WIDTH ----      5.6200000 inch
      RIM DIAMETER -----  3.0 inch
      AXLE DIAMETER ---- 1.4529230 inch
      RIM FLANGE THICKNESS -- 0.11374864 inch
=====================================================================
          MAIN LEG UNIT DETAILS .....
=====================================================================
      MAIN WHEEL PRESSURE ---- 111.46000  psi
      TYRE DIAMETER ----  29.400000   inch
      TYRE WIDTH ---- 7.8500000  inch
      RIM DIA OF THE MAIN WHEEL ----  16.0 inchs
      AXLE DIA OF THE MAIN WHEEL ----  2.5052710 inchs
      FLANGE THICKNESS OF THE RIM ----0.85178170E-1  inchs
---------------------------------------------------------------------
      TYPE OF THE BRAKEING SYSTEM ---  DISC ---
=====================================================================
      SHOCK ABSORBER
      MAIN WHEEL              OLED-PNUEMATIC
     AUXILLARY WHEEL PNUEMATIC
=====================================================================
               ......END OF DETAILS .....
=====================================================================
NIL
SEOFs
<13>RECORDFILE
RECORD FILE DSK: SESS6 CLOSED 19-MAR-87 22:38:34
```

```
RECORD FILE DSK: SESS6 OPENED 19-MAR-87 22:35:48
NIL
<11>(GOAL (START))
(QUESTION PLEASE SPECIFY THE WEIGHT OF THE AIRCRAFT IN POUNDS) >8930
==================================================================
1 AGRICULTURAL PURPOSE                              TYPE  A1
2 LIGHT TRANSPORT 1 2 3 4 SEATER      TYPE A2
3 TRAINER 1 2 SEATER                                TYPE A3
4 EXECUTIVE TRANSPORT 4-8 SEATER      TYPE A4
5 UTILITY AIRCRAFT                    TYPE A5
6 LIGHT,AMETURE A/C                                 TYPE A6
7 FIGHTERS                            TYPE A7
8 PASSANGER,AIRSERVICE                              TYPE A8
9 CARGO TRANSPORT                     TYPE A9
10 SPORTS PLANES                      TYPE A10
=====================================================================
(QUESTION PLEASE SELECT FROM THE ABOVE TABLE AND ANSWER) >A5
==========================================================================================
        OLD DESIGN DETAIL
==========================================================================================
     DESIGN NO =              NO3
     PURPOSE OF THE A/C                A5
     WEIGHT OF THIS A/C  =              8930
LANDING GEAR TYPE    PN
--------------------------------------------------------------------------------------
LOCATION DETAIL ...
         WHEEL BASE = 7.8315134                      WHEEL TRACK = 5.90625
--------------------------------------------------------------------------------
         AUX-WHEEL DETAIL
         ....................
     PRESSURE  = 101.66666  psi              TYRE DIA = 18.0  inchs
      TYRE WIDTH = 5.6200000  inchs                           RIM DIA = 8.0
     AXEL DIA = 1.1529230 WHEEL FLANGE THICKNESS = 0.11374854
--------------------------------------------------------------------------------
         MAIN WHEEL DETAIL
         ..........................
     PRESSURE = 111.46000   psi              TYRE DIA = 29.400000  inchs
      TYRE WIDTH = 7.8500000  inchs                           RIM DIA = 16.0
     AXLE DIA = 2.6052710  inchs       WHEEL FLANGE THICKNESS = 0.85178170E-1
--------------------------------------------------------------------------------------
         TYPE OF BRAKING SYSTEM......   DISC
=====================================================================================
TYPE   CON     FOR CONTINUE >CON
 TYPE THE OPTION AS INDICATED   BELOW
-------------------------------------------------------------------------------------
          OPTION                     SHORT FORM TO BE TYPED
--------------------------------------------------------------------------------------
-
     DESIGN COMPLETELY ACCEPTABLE                        OK  <THAT DESIGN NO>

DESIGN ACCEPTABLE AFTER ALTERATION                  ALTER   <THAT DESIGN NO >
     FURTHER SEARCH DESIRED                        SEARCH < XX >
     A NEW DESIGN DESIRED                          NEW   <NEW DESIGN NO>
=====================================================================================
(QUESTION PLEASE TYPE YOUR OPINION NOW) >ALTER NO3
```

```
PLEASE TYPE A NEW DESIGN NO .....................>NO6
OLD DESIGN PARAMETERS ARE LISTED BELOW , GIVE OPENION BY TYPING   change  OR
 no
------------------------------------------------------------------------------
        name of the parameter                old value            opinion/newvalue
------------------------------------------------------------------------------
       FRICTION-COEF  GROUND                         0.64999999              >NO
       % WEIGHT ACTING ON AUX-WHEEL                 12.0              >NO
        CG VALUE OF THE A/C                          4.5                 >CHANGE
 PLEASE TYPE NEW VALUE OF CG ....                >5.25
        ASPECT-RATIO VALUE                           5.6000000                 >NO
       STALLING VELOCITY OF A/C                 103.0                >NO
      FRICTION-COEF OF BRAKING MATERIAL                  0.75                 >NO
      TYPE OF LANDING GEAR                   PN                >NO
         BRAKING SYSTEM                      DISC                 >NO
..............................................
DESIGN WILL BE DONE FOR NOSEWHEEL-TYPE
...................................
---------------------------------------------
      UNDERCARRIAGE LOCATION DETAILS
FORE LOCATION                   1.0964118  feet
AFT LOCATION                    8.0403538  feet
WHEEL BASE                      9.1367658  feet
WHEEL TRACK                     6.890625  feet
---------------------------------------------
 DOING LOCATION CALCULATION
YES
Should I try for another answer (Y/N):>N
```

```
<12>TY RESULT
=======================================================================
     DESIGN DETAIL OF UNDER CARRIAGE
=======================================================================
     DESIGN NUMBER -----------  ND6
-----------------------------------------------------------------------
      PURPOSE OF THE AIRCRAFT -----  A5
-----------------------------------------------------------------------
     WEIGHT OF THE A/C -----  8930
     TYPE OF LANDING GEAR ----  PN
-----------------------------------------------------------------------
     LOCATION DETAILS
-----------------------------------------------------------------------
     WHEEL BASE ------  9.1357658
     WHEEL TRACK -----  5.890625
=======================================================================
      AUXLLARY LEG UNIT DETAIL ......
=======================================================================
      AUX-WHEEL PRESSURE --- 101.66666  psi
      TYRE DIAMETER  ---- 18.0  inch
      TYRE WIDTH ----      5.6200000 inch
      RIM DIAMETER -----  8.0 inch
      AXLE DIAMETER ---- 1.1529230 inch
      RIM FLANGE THICKNESS -- 0.11374864 inch
=======================================================================
          MAIN LEG UNIT DETAILS .....
=======================================================================
      MAIN WHEEL PRESSURE ---- 111.46000  psi
      TYRE DIAMETER ----  29.400000   inch
      TYRE WIDTH ----  7.8500000  inch
      RIM DIA OF THE MAIN WHEEL ----  16.0 inchs
      AXLE DIA OF THE MAIN WHEEL ----  2.5052710 inchs
      FLANGE THICKNESS OF THE RIM ----0.85178170E-1  inchs
-----------------------------------------------------------------------
      TYPE OF THE BRAKEING SYSTEM ---  DISC ---
=======================================================================
      SHOCK ABSORBER
      MAIN WHEEL              OLEO-PNUEMATIC
     AUXILLARY WHEEL PNUEMATIC
=======================================================================
              ......END OF DETAILS .....
=======================================================================
NIL
$EOF$
<13>RECORDFILE
RECORD FILE DSK: SESS6 CLOSED 19-MAR-87 22:38:34
```

```
RECORD FILE DSK: SESS6 OPENED 19-MAR-87 22:35:48
NIL
<11>(GOAL (START))
(QUESTION PLEASE SPECIFY THE WEIGHT OF THE AIRCRAFT IN POUNDS) >8930
=================================================================
1 AGRICULTURAL PURPOSE                          TYPE  A1
2 LIGHT TRANSPORT 1 2 3 4 SEATER      TYPE A2
3 TRAINER 1 2 SEATER                            TYPE A3
4 EXECUTIVE TRANSPORT 4-8 SEATER      TYPE A4
5 UTILITY AIRCRAFT                    TYPE A5
6 LIGHT,AMETURE A/C.                            TYPE A6
7 FIGHTERS                            TYPE A7
8 PASSANGER,AIRSERVICE                          TYPE A8
9 CARGO TRANSPORT                     TYPE A9
10 SPORTS PLANES                      TYPE A10
=======================================================================
(QUESTION PLEASE SELECT FROM THE ABOVE TABLE AND ANSWER) >A5
=========================================================================================
          OLD DESIGN DETAIL
=========================================================================================
      DESIGN NO =              ND3
      PURPOSE OF THE A/C                 A5
       WEIGHT OF THIS A/C   =             8930
LANDING GEAR TYPE      PN
-------------------------------------------------------------------------------------
LOCATION DETAIL ...
          WHEEL BASE = 7.8315134                         WHEEL TRACK = 5.90625
--------------------------------------------------------------------------------
          AUX-WHEEL DETAIL
          ....................
      PRESSURE  = 101.66666  psi                TYRE DIA = 18.0  inchs
       TYRE WIDTH = 5.6200000  inchs                               RIM DIA = 8.0
      AXEL DIA = 1.1529230 WHEEL FLANGE THICKNESS = 0.11374864
--------------------------------------------------------------------------------
          MAIN WHEEL DETAIL
          ........................
      PRESSURE = 111.46000   psi                TYRE DIA = 29.400000  inchs
       TYRE WIDTH = 7.8500000  inchs                               RIM DIA = 16.0
      AXLE DIA = 2.6052710  inchs         WHEEL FLANGE THICKNESS = 0.85178170E-1
-------------------------------------------------------------------------------------
          TYPE OF BRAKING SYSTEM......   DISC
=====================================================================================
TYPE   CON      FOR CONTINUE >CON
  TYPE THE OPTION AS INDICATED   BELOW
-------------------------------------------------------------------------------------
          OPTION                         SHORT FORM TO BE TYPED
-----------------------------------------------------------------------------------------
-
      DESIGN COMPLETELY ACCEPTABLE                          OK  <THAT DESIGN NO>

DESIGN ACCEPTABLE AFTER ALTERATION                      ALTER    <THAT DESIGN NO >
      FURTHER SEARCH DESIRED                           SEARCH < XX >
      A NEW DESIGN DESIRED                             NEW    <NEW DESIGN NO>
=====================================================================================
(QUESTION PLEASE TYPE YOUR OPINION NOW) >ALTER ND3
```

```
PLEASE TYPE A NEW DESIGN NO ........................>NO6
OLD DESIGN PARAMETERS ARE LISTED BELOW , GIVE OPENION BY TYPING   change  OR
 no
-----------------------------------------------------------------------------
         name of the parameter                   old value             opinion/newvalue
-----------------------------------------------------------------------------
        FRICTION-COEF  GROUND                           0.64999999                >NO
        % WEIGHT ACTING ON AUX-WHEEL                   12.0                 >NO
          CG VALUE OF THE A/C                            4.5                  >CHANGE
 PLEASE TYPE NEW VALUE OF CG ....               >5.25
         ASPECT-RATIO VALUE                              5.6000000                >NO
        STALLING VELOCITY OF A/C                103.0                  >NO
       FRICTION-COEF OF BRAKING MATERIAL                0.75                >NO
       TYPE OF LANDING GEAR                 PN                 >NO
          BRAKING SYSTEM                    DISC                   >NO
..................................................
DESIGN WILL BE DONE FOR NOSEWHEEL-TYPE
..........................................
-------------------------------------------------
       UNDERCARRIAGE LOCATION DETAILS
FORE LOCATION                    1.0964118  feet
AFT LOCATION                     8.0403538  feet
WHEEL BASE                       9.1367658  feet
WHEEL TRACK                      6.890625  feet
-------------------------------------------------
 DOING LOCATION CALCULATION
YES
Should I try for another answer (Y/N):>N
```

```
<12>TY RESULT
=================================================================
     DESIGN DETAIL OF UNDER CARRIAGE
=================================================================
     DESIGN NUMBER ----------  ND6
-----------------------------------------------------------------
      PURPOSE OF THE AIRCRAFT -----  A5
-----------------------------------------------------------------
     WEIGHT OF THE A/C -----  8930
     TYPE OF LANDING GEAR ----  PN
-----------------------------------------------------------------
     LOCATION DETAILS
-----------------------------------------------------------------
     WHEEL BASE ------  9.1367658
     WHEEL TRACK -----  6.890625
=================================================================
      AUXLLARY LEG UNIT DETAIL ......
=================================================================
      AUX-WHEEL PRESSURE --- 101.66666  psi
      TYRE DIAMETER  ---- 18.0  inch
      TYRE WIDTH ----    5.6200000 inch
      RIM DIAMETER -----  8.0 inch
      AXLE DIAMETER ---- 1.1529230 inch
      RIM FLANGE THICKNESS -- 0.11374864 inch
=================================================================
          MAIN LEG UNIT DETAILS .....
=================================================================
      MAIN WHEEL PRESSURE ---- 111.46000  psi
      TYRE DIAMETER ----  29.400000   inch
      TYRE WIDTH ----  7.8500000  inch
      RIM DIA OF THE MAIN WHEEL ----  16.0 inchs
      AXLE DIA OF THE MAIN WHEEL ----  2.5052710 inchs
      FLANGE THICKNESS OF THE RIM ----0.65178170E-1  inchs
-----------------------------------------------------------------
      TYPE OF THE BRAKEING SYSTEM ---  DISC ---
=================================================================
      SHOCK ABSORBER
      MAIN WHEEL             OLEO-PNUEMATIC
    AUXILLARY WHEEL PNUEMATIC
=================================================================
              ......END OF DETAILS .....
=================================================================
NIL
$EOFs
<13>RECORDFILE
RECORD FILE DSK: SESS6 CLOSED 19-MAR-87 22:38:34
```

```
OK
<20>TY RESULT
==============================================================
     DESIGN DETAIL OF UNDER CARRIAGE
==============================================================
     DESIGN NUMBER ----------  04
--------------------------------------------------------------
      PURPOSE OF THE AIRCRAFT -----  A5
--------------------------------------------------------------
     WEIGHT OF THE A/C -----  8930
     TYPE OF LANDING GEAR ----  PN
--------------------------------------------------------------
     LOCATION DETAILS
--------------------------------------------------------------
     WHEEL BASE ------  7.8315134
     WHEEL TRACK -----  5.90625
==============================================================
      AUXLLARY LEG UNIT DETAIL ......
==============================================================
      AUX-WHEEL PRESSURE --- 101.66666  psi
      TYRE DIAMETER  ---- 18.0  inch
      TYRE WIDTH ----      5.6200000 inch
      RIM DIAMETER -----  8.0 inch
      AXLE DIAMETER ---- 1.4529230 inch
      RIM FLANGE THICKNESS -- 0.11374864 inch
==============================================================
          MAIN LEG UNIT DETAILS .....
==============================================================
      MAIN WHEEL PRESSURE ----  111.46000  psi
      TYRE DIAMETER ----  29.400000   inch
      TYRE WIDTH ----  7.8500000  inch
      RIM DIA OF THE MAIN WHEEL ----  16.0 inchs
      AXLE DIA OF THE MAIN WHEEL ----  2.5052710 inchs
      FLANGE THICKNESS OF THE RIM ----0.85178171E-1  inchs
--------------------------------------------------------------
      TYPE OF THE BRAKEING SYSTEM ---  DISC ---
==============================================================
      SHOCK ABSORBER
      MAIN WHEEL              OLEO-PNUEMATIC
    AUXILLARY WHEEL PNUEMATIC
==============================================================
              ......END OF DETAILS .....
==============================================================
NIL
$EOF$
<21>RECORDFILE
RECORD FILE DSK: SESS4 CLOSED 19-MAR-87 02:30:02
```

```
================================================================================
        OOO DESIGN DETAIL
================================================================================
     DESIGN NO =              .02
     PURPOSE OF THE A/C               A5
     WEIGHT OF THIS A/C   =            8930
LANDING GEAR TYPE     PN
--------------------------------------------------------------------------------
LOCATION DETAIL ...
        WHEEL BASE = 7.8315134                    WHEEL TRACK = 5.90625
--------------------------------------------------------------------------------
        AUX-WHEEL DETAIL
        ....................
     PRESSURE  = 101.66666   psi            TYRE DIA = 18.0  inchs
      TYRE WIDTH = 5.6200000  inchs                         RIM DIA = 8.0
     AXEL DIA = 1.4529230 WHEEL FLANGE THICKNESS = 0.11374364
--------------------------------------------------------------------------------
        MAIN WHEEL DETAIL
        .........................
     PRESSURE = 111.46000   psi              TYRE DIA = 29.400000  inchs
      TYRE WIDTH = 7.8500000  inchs                         RIM DIA = 16.0
     AXLE DIA = 2.5052710  inchs          WHEEL FLANGE THICKNESS = 0.85178171E-1
--------------------------------------------------------------------------------
        TYPE OF BRAKING SYSTEM......   DISC
================================================================================
TYPE   CON      FOR CONTINUE >CON
  TYPE THE OPTION AS INDICATED   BELOW
--------------------------------------------------------------------------------
         OPTION                           SHORT FORM TO BE TYPED
--------------------------------------------------------------------------------
-
     DESIGN COMPLETELY ACCEPTABLE                       OK  <THAT DESIGN NO>

DESIGN ACCEPTABLE AFTER ALTERATION                ALTER    <THAT DESIGN NO >
     FURTHER SEARCH DESIRED                     SEARCH < XX >
     A NEW DESIGN DESIRED                       NEW    <NEW DESIGN NO>
================================================================================
(QUESTION PLEASE TYPE YOUR OPINION NOW) >OK 03
(QUESTION PLEASE TYPE NEW DESIGN NUMBER) >04
YES
Should I try for another answer (Y/N):>N
```